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**The contribution of lean thinking to the maintenance
of manufacturing systems**

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The contribution of lean thinking to the maintenance of manufacturing systems

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Abstract

Despite many significant contributions and advances of lean thinking recorded in articles, books, and industrial case studies, its impact upon the maintenance function has not been fully investigated. From a maintenance perspective, excluding TPM, little or no insight into the use of lean thinking concepts in maintenance can be found in the literature, despite prominent contributors advocating greater management and business integration.

An objective of the research described in this thesis was to satisfy the need for industry to understand the contribution of lean thinking to the maintenance of manufacturing systems. A research hypothesis (lean thinking improves the effectiveness of the maintenance function) was therefore devised that aimed to bridge this gap in knowledge in which the researcher developed two new tools alongside existing methodologies for further investigation. The first novel research tool, a lean concept reference framework, was used to comprehensibly represent lean thinking concepts possible within a company, and maintenance in particular. The second, an overall measure of maintenance performance comprised a number of indicators that signify change through maintenance activity. This was used to reflect the impact of lean concept use by maintenance through change in activity performance.

The research investigates the current views of lean thinking and maintenance within the U.K, and particularly in the automotive industry. It exposes the diversity of maintenance as a function within this industry, and highlights the scope of lean concept use and understanding. As an outcome of the research, it was found that each company investigated had different reasons for adopting and using lean concepts within their maintenance function. Similarly, each company differed in the management and use of their performance data. Nonetheless, all those investigated accepted the role of lean concept use within maintenance, and considered certain elements useful. These elements were used as an aggregation of tools to assist maintenance in their activities rather than using them to develop an alternative maintenance strategy.

However, perception of lean concept use, and the perceived benefits gained differed according to different viewpoints. Although it was generally accepted that lean use brought about or improved overall skills, and helped provide the basis of a more robust and standardised maintenance department, concern was expressed concerning the difficulty in translating essentially lean manufacturing techniques to suit maintenance.

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Nikki, my wife, for her support especially during the last year, whose unlimited patience, generosity and understanding have enabled me to complete this thesis in the comfort of a warm home, with electricity and hot water, with meals provided (occasionally), and all my bills paid for me.

Also, I would like to thank my three delightful children, who allowed me to work unhindered, without a word of dissent and complaint, and never switching off my computer when I was working on it!

I would also like to take the opportunity to recount some endearing comments made to me by some of the people who took part in my research.

“I’ll show you something you won’t find in them fancy college books”

“Twenty six years I’ve been here, man and boy, that’s why I get to park my car outside the workshop!”

“I’ve got good lads working for me, they do as they are told!”

“You left school in 1978? We were on strike then!”

THANK YOU

Publications

Davies, C. and Greenough, R.M. (2000), The use of information systems in fault diagnosis, *16th National conference on manufacturing research*, London, (U.K), pp. 37-42

Davies, C, and Greenough, R.M, (2001), Maintenance survey: Identification of lean thinking within maintenance, *17th National conference on manufacturing research*, Cardiff, (U.K), pp. 37-42

Davies, C. and Greenough, R.M. (2002), Measuring the effectiveness of lean thinking activities within maintenance, *Maintenance journal*, Australia, 15 (3), pp. 8-14,

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Glossary of terms

BSI	British Standards Institute
CI	Continuous Improvement
CMMS	Computerised Maintenance Management System
DTI	Department of Trade and Industry
EEF	Engineering Employers Federation
EEM	Early Equipment Management
ERP	Enterprise Resource Planning
ES	Expert System
FPS	Ford Production System
FTPM	Ford Total Productive Maintenance
IETM	Interactive Electronic Technical Manuals
JIT	Just-In-Time
LCC	Life Cycle Costing
MMIS	Maintenance Management Information System
MMT	Maintenance Management Tool
MSG	Maintenance (standards) Steering Group
MTBF	Mean time between failure
MTTR	Mean Time To Repair
NEPT	New Equipment Procurement Team

OEE	Overall Equipment Effectiveness
PDCA	Plan Do Check Action
PM	Preventative Maintenance
QFD	Quality Function Deployment
RCM	Reliability Centred Maintenance
TEI	Total Employee Involvement
TPM	Total Productive Maintenance
TPS	Toyota Production System
TQM	Total Quality Management

Chapter One

Introduction

1.1 Introduction

In this preliminary chapter, the motivation for the research is expressed. The subsequent aim of the research is to understand ‘the contribution of lean thinking to the maintenance of manufacturing systems’ and therefore to identify lean concept uses by the maintenance function. The following chapters explore the aims and objectives of the research and intend to investigate current knowledge, identify the problem and fill the gap in knowledge.

The research follows an appropriate method to investigate the problem, develops appropriate tools for investigation of the problem, then presents the findings and conclusions as based on current examples within industry. Impartiality is sought by seeking and using standard definitions throughout the thesis for those issues under discussion. Where possible, these definitions help to explain within context, the practical implications in support of the research hypothesis.

A schema for the thesis is presented in this chapter, and sets the context for investigation, by summarising the research background and motivation to investigate the current view of lean thinking and maintenance within the U.K, and the scope of lean concept use and understanding within this function. This chapter also presents the thesis structure in terms of how the research is undertaken.

1.2 Research background and motivation

Exemplified by the Toyota approach to manufacturing, the synthesis of advanced manufacturing practices by Womack *et al.* published in 1990, and with Womack and Jones’s development and definition between 1994 and 1996 of lean thinking (1994; 1996b), interest in ‘lean’ has certainly increased (see chapter two). So much so, that industries not influenced by the principles and demonstrated benefits of lean, are becoming fewer (Katayama and Bennett, 1996). Nonetheless, a lack of evidence suggests that the connection between lean thinking and the maintenance function beyond the scope of TPM have not been seriously considered. Similarly, from a maintenance perspective, greater management and business integration has been

advocated (e.g., Kelly, 1997; Bamber *et al.*, 1999, etc.), yet excluding TPM, maintenance literature provides little or no insight to the issue of lean thinking perceived by Womack, Jones and others. /

Survey research to verify initial literature findings and seek current attitudes toward the use of lean thinking by maintenance found that lean concepts other than TPM are used by maintenance. Nonetheless the survey could not identify generic lean practice implementation or a comprehensive list of lean activities used by maintenance (Davies and Greenough, 2001). A literature review identified lean and maintenance as separate contributors to the effectiveness of an organisation, but could not show the extent of use, or if benefits could be gained from the integration of lean thinking and maintenance. Therefore, it is this gap in knowledge that has provided the motivation for this researcher to continue the investigation of lean thinking and the maintenance issue.

1.3 Thesis structure

The thesis structure depicted in Figure 1.1 is as follows

Chapter two - Literature review: Details the background and justification for this research, the research problem, research aim and hypothesis: 'Lean thinking improves the effectiveness of the maintenance function.'

Chapter three - Research methodology: The research methodology adopted for this research is exposed

Chapter four - Overview of lean thinking reference framework: Presents and discusses the development of a lean reference framework, representative of lean concept use possible within a company and maintenance in particular. The framework provides forms of understanding, identification and measurement for investigation

Chapter five - Maintenance performance indicators: Presents and discusses the development of an overall measure of maintenance performance comprising consequence variables, which through maintenance activity may possibly relate to the use of certain lean concepts. In particular, those concepts within the lean reference framework, in terms of their possible contribution to maintenance that could provide quantitative feedback. Data collection techniques are also discussed

Chapter six - Industrial investigation through case study research: Conveys the case study research to investigate lean concept use by maintenance practitioners both qualitatively and quantitatively to answer the research hypothesis

Chapter seven - Discussions and conclusions: The findings and contributions from the previous chapters are discussed, compared and concluded here, and are presented to the extent in which the research supports the hypothesis and contribution to knowledge.

As this researcher has identified that literature provides an incomplete picture of lean concept as used by maintenance, this has formed the basis for the research question: 'How does lean thinking improve the effectiveness of the maintenance function?' This question is to be developed by the following hypothesis: 'Lean thinking improves the effectiveness of the maintenance function' and applied to the research as a basis for further investigation.

A generic programme of lean concept implementation, or a comprehensive list of lean activities practised by maintenance, is beyond the scope of this research, however it is hoped that a contribution to knowledge will have been achieved by the completion of this investigation.

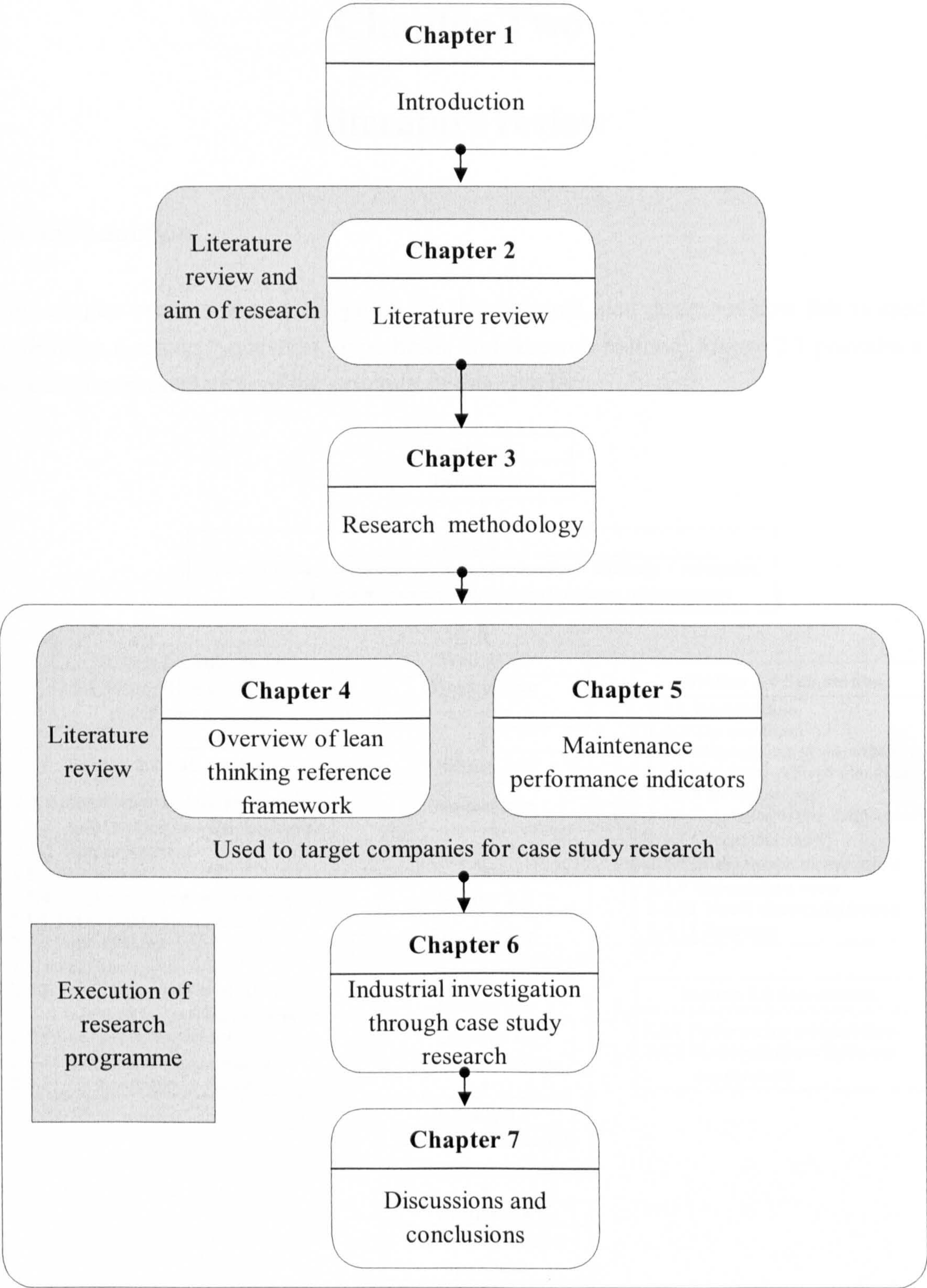


Figure 1.1 Structure of thesis

Chapter Two

Literature review

2.1 Introduction

This chapter presents the investigation for this research, and describes how this is used to develop a research question, hypothesis, and research method. Figure 2.1 provides a schematic representation of the structure of this chapter:

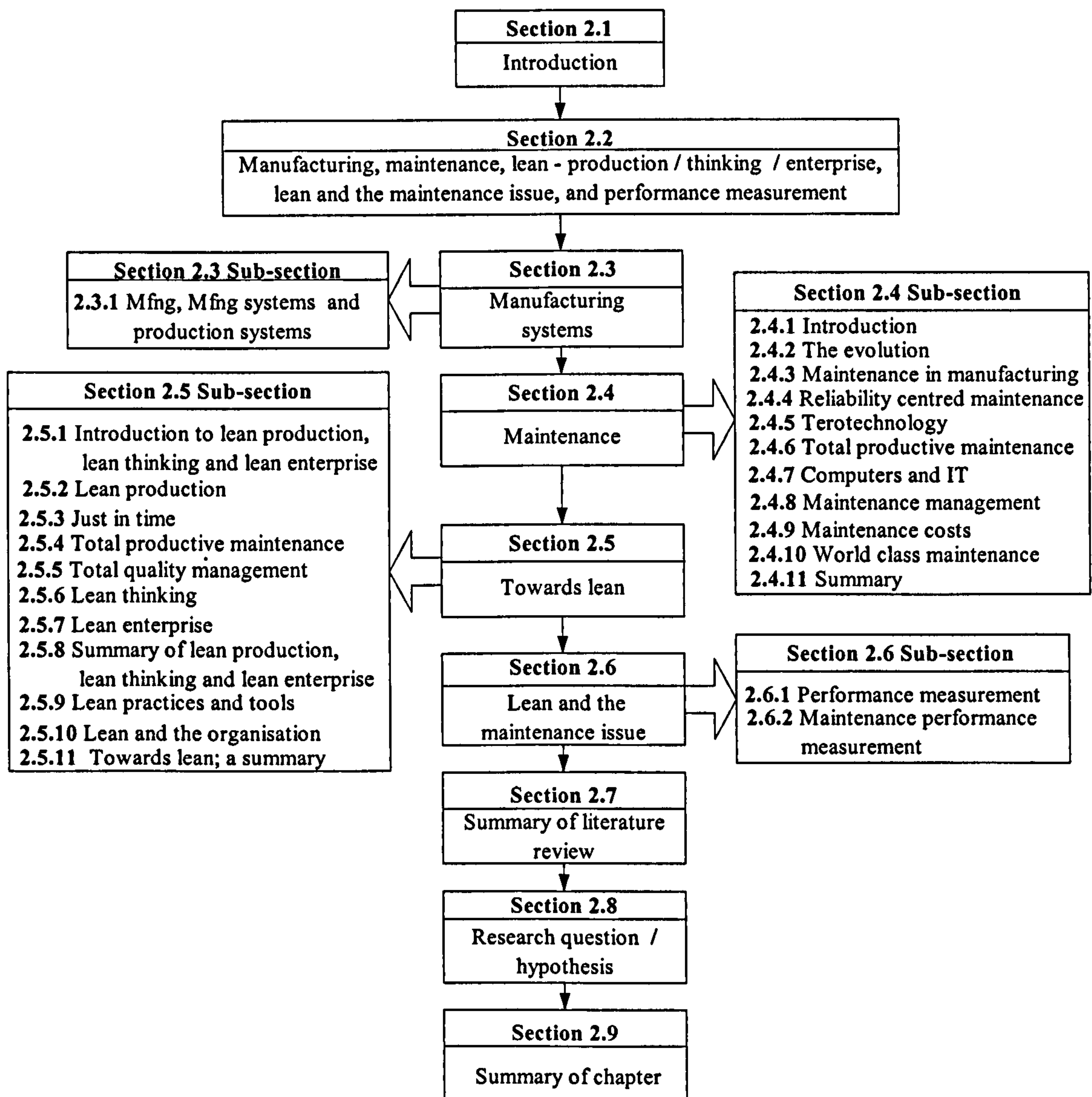


Figure 2.1 Layout of chapter two

2.2 Manufacturing, maintenance, lean- production / thinking / enterprise, lean and the maintenance issue, and performance measurement

Examination of the practical, management and research issues concerning the combined aspect of manufacturing systems, maintenance, lean production, lean thinking, lean enterprise, lean and the maintenance issue, and measures of performance required for the completion of this study are discussed here. Where possible throughout the chapter, standard definitions of concepts and practices are used to avoid bias and provide a commonly recognisable reference for the researcher and those being researched.

This chapter will demonstrate the need for maintenance to align itself with the business objectives of an organisation, and the necessity for performance measures to indicate improvement within the organisation, and maintenance in particular, through lean activity.

2.3 Manufacturing systems

Manufacturing terminology can be found in a variety of publications (e.g., Chryssolouris, 1992; Hopp and Spearman, 2000; Black, 1991) and dictionaries highlighting broad and specific areas of interest. However, the aim of this section is not to provide a universal definition of manufacturing, manufacturing systems, or production systems, but to specify the terminology used within the scope of this research.

2.3.1 Manufacturing, manufacturing systems and production systems

Chryssolouris (1992) describes manufacturing as the ‘transformation of materials and information into goods for the satisfaction of human needs’. In addition, it can be thought of as a system where product design is the initial stage, and delivery of finished goods is the final output. Hopp and Spearman (2000) state that a manufacturing system is “an objective-oriented network of processes through which entities flow”. In this context, ‘objective’ refers to low cost – high sales, etc.; ‘processes’ refers to terms of physical processes that interact with each other, and ‘entities’ describes parts to be manufactured or information to control.

Black (1991), states that production systems differentiate from manufacturing and manufacturing systems in that they cover all activities within a company (including

design, selection of factory layouts and facilities) except the physical transformation process.

By way of an overall explanation, there is little difference between what manufacturing is, and what manufacturing systems are. As such, within the scope of this research the terminology may be interchangeable without losing impact or significance, therefore for the purpose of this research, Blacks' definition of a production system will be used.

From a practical point of view, the principal definitions of manufacturing and production systems are representative for any type of manufacturing situation whether they are process, batch or project based industry types, etc. However, different approaches to how the definitions are applied on an individual basis will vary between different styles of organisation and their manufacturing type. Of the many books and articles available, Slack *et al.* (1998) and Hopp and Spearman (2000), provide clear explanations of the commonly known areas of practical manufacturing process types. The main types discussed by these authors are project, jobbing, batch, mass and continuous manufacturing, each in their own way suited to different types of requirement:

- 1 Project based manufacturers - focus on low volume specialised processes such as shipbuilding
- 2 Jobbing manufacturers - focus on multiple products with low volume (e.g., heavy equipment)
- 3 Batch manufacturers - concentrate on a few major products with less process variety (e.g., machine tooling, food, etc.)
- 4 Mass producers - focus on high volumes with narrow variety (e.g., auto assembly, CD production, etc.)
- 5 Continuous manufacturing - operates over long periods of time, with little or no product or process variation or stoppage, these are generally power suppliers, oil and gas producers, and refineries.

An increasing demand on manufacturing productivity, quality and availability within the context of the definitions and types of manufacturing presented here has meant that machines are becoming more complex, capital intensive and numerous (DTI, 1991; Swanson, 1999). As such, the changing technology, increased customer expectation,

supplier attitudes and increased competition has also meant that maintenance of these systems has been without proper integration of suitable techniques (Coetzee, 1999). In particular, those that suit the different approaches to manufacturing that have been sought to improve efficiency, effectiveness, capability, flexibility and competitiveness. These issues are presented and discussed on their own merit where appropriate in greater detail within the following sections.

2.4 Maintenance

This section discusses the subject of maintenance, in particular the maintenance of manufacturing systems. Firstly, it provides an introduction to maintenance through definition then presents the evolution of maintenance, and looks at maintenance in manufacturing from a practical, management, and cost point-of-view.

2.4.1 Introduction to maintenance

The UK Department of Trade and Industry (DTI, 1991), defines maintenance as:

“The management, control, execution and quality of those activities that will ensure optimum levels of availability and overall performance of plant are achieved, in order to meet business objectives”.

Similarly, the British Standard definition of maintenance is:

“The combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required function” (BSI, 1993).

British Standard 3811 (1993), contains an extensive list of activities and classifications that contribute to, or support the definition of maintenance. Previously, the same standard (BS3811, 1984), classified maintenance into various activities using a hierarchy of terminology (Greenough, 1999). As such, Figure 2.2 presents the various forms of maintenance, and Table 2.1 provides the definitions:

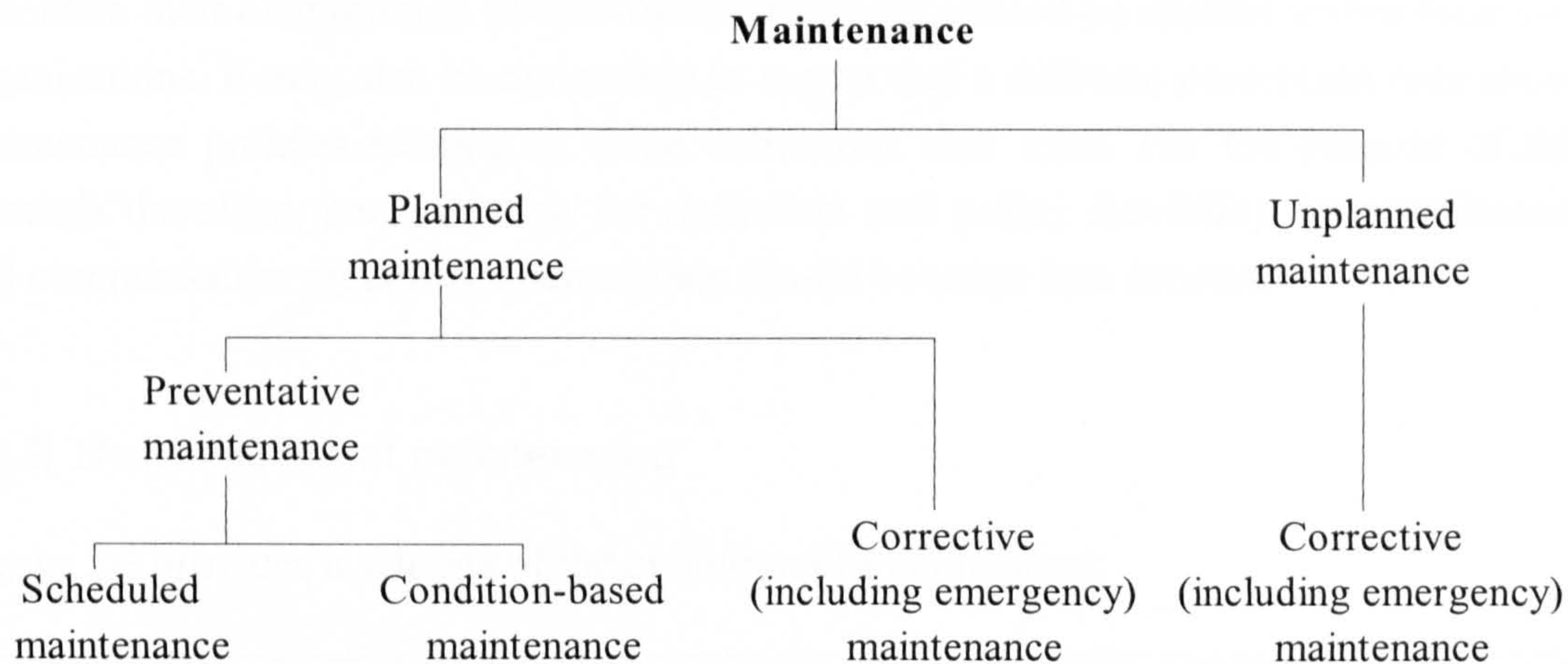


Figure 2.2 Various forms of maintenance (BS3811, 1984, cited in Greenough, 1999)

Terminology	Definition
Maintenance	See previous description
Planned maintenance	The maintenance organised and carried out with forethought, control and the use of records to a predetermined plan NOTE: Preventive maintenance is always part of planned maintenance; corrective maintenance may or may not be
Unplanned maintenance	The maintenance carried out to no predetermined plan
Preventative maintenance	The maintenance carried out at predetermined intervals, or according to prescribed criteria, and intended to reduce the probability of failure, or the degradation of the functioning of an item
Scheduled maintenance	The preventive maintenance carried out in accordance with an established time schedule
Condition-based maintenance	The maintenance carried out according to the need, indicated by condition monitoring. NOTE: Condition monitoring is the continuous or periodic measurement and interpretation of data to indicate the condition of an item to determine the need for maintenance, normally carried out with the item in operation, in an operable state or removed but not subject to major dismantling.
Corrective maintenance	The maintenance carried out after fault recognition, and intended to put an item into a state in which it can perform a required function NOTE: Emergency maintenance referred to in figure 2.2 is the maintenance that is necessary to put in hand immediately to avoid serious consequences

Table 2.1 Definitions of the various forms of maintenance (BS3811, 1993)

The definition of maintenance and its various forms is therefore introduced; the purpose and definition are distinct and as such are intended to be a theme for reference. For this reason, it is possible for different companies, with different management approaches, to

formulate their own opinion of how these definitions should be applied within their own organisations. It may also be reasonable to expect that a different perception concerning maintenance policies relating to these definitions also exist. For the purpose of this research therefore, consideration for definition and policy flexibility by practitioners and commentators regarding maintenance should be taken into account.

2.4.2 The evolution of maintenance

Figure 2.3 provides a schema of the evolution of maintenance:

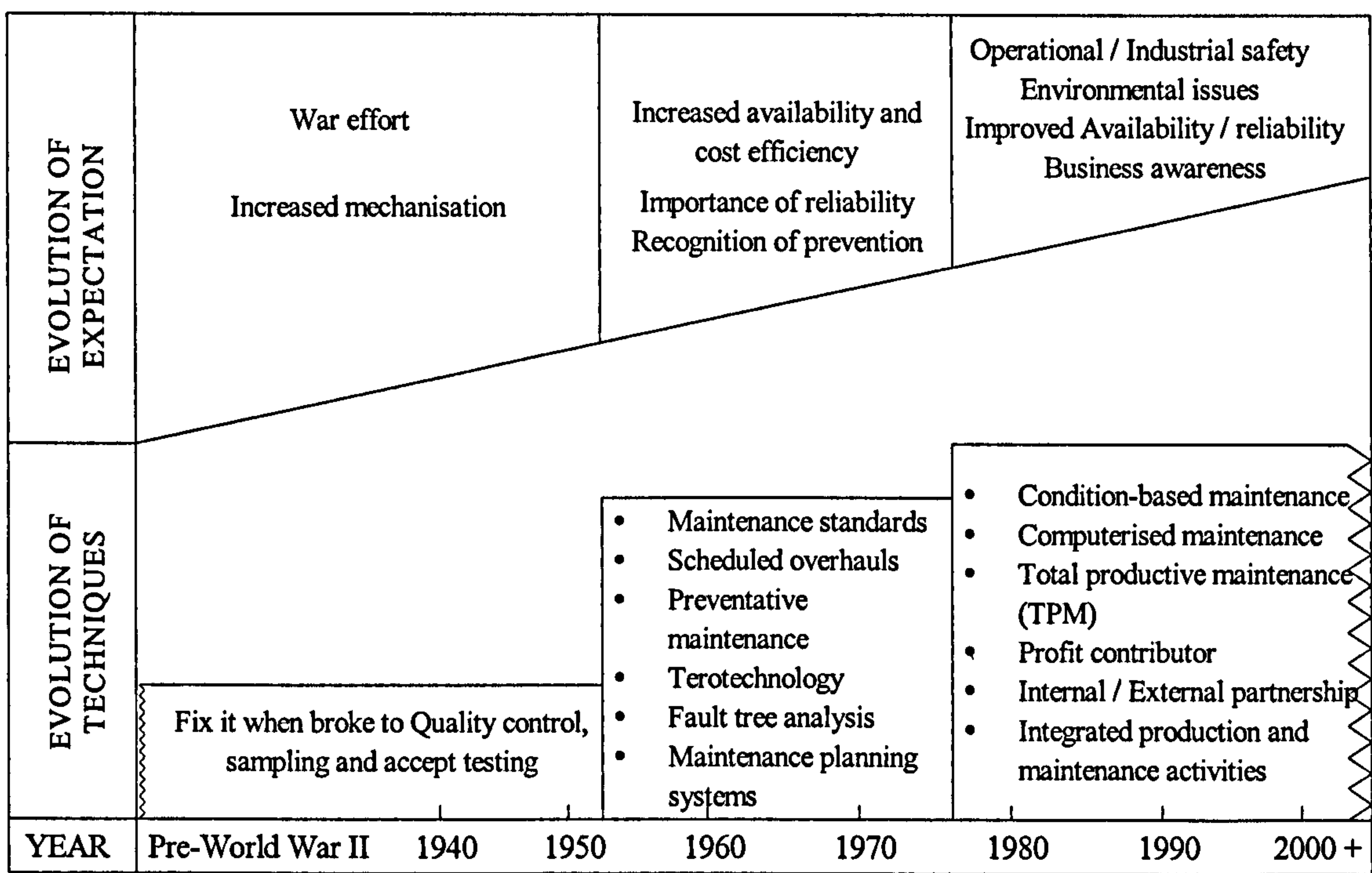


Figure 2.3 The evolution of maintenance (after Van Rijn and Scholten, 1996, and Sherwin, 2000)

2.4.3 Maintenance in manufacturing

As Figure 2.3 illustrates, the case for maintenance improvement has certainly evolved. Until recently however, manufacturers saw little need for developing adequate maintenance strategies in line with increasingly sophisticated manufacturing technology. This was mostly due to the relative ease with which excess stocks could be built and carried, or overtime and extra shifts worked, and spare capacity, as extra machines or quick off load sub-contract, could be arranged (DTI, 1991). In short, maintenance has lagged behind the advances of manufacturing.

It could be suggested that the principal responsibility of maintenance is to provide a service to an organisation that enhances its ability to make a profit. One of the important reasons for this is that machines and manufacturing processes have become more complex and capital intensive. The effectiveness of the maintenance function is therefore a major management and technical issue through increased demand on productivity, quality, and availability. It is also considered unlikely that increased competitive pressure, necessitating cost effectiveness, manufacturing reliability, and process improvement will diminish the importance or principle responsibility of maintenance now or in the future (DTI, 1991; Luxhoj *et al.* 1997; Jonsson, 1997; Blanchard, 1997; Tsang, 1998; Bamber *et al.* 1999; Coetzee, 1999; Holman *et al.* 2000; Kutucuoglu *et al.* 2001; Swanson, 1999, 2001).

The theme (or paradigm) expressing the role of maintenance, to ‘satisfy current and future manufacturing demands’, cannot be viewed as an optimum representation; its target will always move with time. Nonetheless, different approaches have been developed (through time) or are being used within the paradigm, whose aim was or is to keep up with the moving target. These approaches are discussed here:

2.4.4 Reliability centred maintenance (RCM)

RCM contributes very well to the issue of machine reliability within maintenance. However, the focus is in relative isolation to the ideal. Its main function is still the elementary failure process, rather than integrity within the organisation and its dynamics. However, computer technology has allowed RCM to become more widely accessible and usable, especially for the process industries such as oil, gas, refinery and chemical.

RCM in principle evolved from a standardised approach to aircraft maintenance management in the early 1960s, through the formation of the maintenance (standards) steering group (MSG). This group published its first handbook in 1968 (MSG-1), and an updated revision, MSG-3 issued in 1993 (Blanchard, 1995; Van Rijn and Sholten, 1996; Sherwin, 2000). Essentially, MSG guidelines were developed for a more practically usable method of reliability engineering, which at the time was becoming more distinctive as a science. Incidentally, reliability engineering had its beginnings during the Second World War, and was used to overcome missile guidance problems, although maintenance was less of an issue because missiles were generally pilotless and not required to return.

2.4.5 Terotechnology

The concept of Terotechnology evolved between 1970 and 1975 within the U.K, based on a 1968 study commissioned by the then Ministry of Technology, on engineering maintenance in the British manufacturing industry (Husband, 1976; Kelly, 1984). Broadly speaking, its principles and methodology were an early attempt at managing the combined issue of manufacturing and its maintenance. Its emphasis allowed the maintenance function to be viewed as a contributor to making profit, as opposed to spending money. The objective, which was also its key concept, was to minimise the whole-life cost of asset ownership through improved activity and communication feedback between maintenance and plant designers.

As important as terotechnology was thought to be, general interest tailed off in the late 1970s because many considered this approach too costly and prohibitively complex. Kelly (1984) refers to a plant procurement case study in the early 1970s by Harvey and Eastburn, where he cites that the main difficulties were cash and time constraints. The approach involved a much higher capital expenditure than the more traditional lowest-bid, lowest-cost, shortest-time approach favoured at that time. Although the key concepts of terotechnology are still discussed, the general feeling was that at the time it was too complex, with an interdependent reliance on too diverse a range of resources to succeed. The British Standards Institution continues to define terotechnology as: “A combination of management, financial, engineering, building and other practices applied to physical assets in pursuit of economic life cycle costs” (BS 3811, 1993).

2.4.6 Total productive maintenance (TPM)

TPM is an approach to maintenance developed by Seiichi Nakajima and introduced in Japan in 1971; publication of the English translation entitled ‘Introduction to TPM’, was in 1988 (Nakajima, 1988). Its philosophy and principles are certainly not detrimental to the paradigm previously discussed. However, as Nakajima states, although TPM and terotechnology have life-cycle costs and participation as a common goal, they differ in terms of their precise target and location of responsibility. Whereas terotechnology involved the equipment supplier, engineering firms, designers and the equipment user, only the equipment user practices TPM. The issue of TPM, and its contribution to maintenance and the organisation, is discussed later in this chapter and throughout subsequent chapters.

A definition of TPM is provided by Bamber *et al.* (1999), citing Rhyne (1990) who considers the main features of TPM as:

“A partnership between the maintenance and production organisations to improve product quality, reduce waste, reduce manufacturing cost, increase equipment availability, and improve the company’s overall state of maintenance”.

In the context of this definition, ‘reduce waste’ refers to production wastes, and are discussed later in the chapter.

Essentially, Nakajima’s explanations of the distinctive features of TPM are such that the building blocks of TPM are:

- 1 Maximise equipment effectiveness (overall effectiveness)
- 2 Establish a thorough system of PM for the equipment’s life span
- 3 Implement by various departments (i.e. engineering, operations, maintenance)
- 4 Involve every single employee, from top management to shopfloor worker
- 5 Promote PM (preventative maintenance) through motivation management: autonomous small group activities.

The practical issues of the building blocks are such that the development activities are:

- 1 Eliminate the six big losses to improve equipment effectiveness
- 2 Introduce automated maintenance programs
- 3 Schedule maintenance programs, for maintenance
- 4 Extend the skills of maintenance and personnel
- 5 Initiate equipment management programs.

It must be noted that the “six big losses” (i.e., equipment failure, set-up and adjustment, idling and minor stoppages, reduced speed, process defects, and reduced yield) are mostly production losses, in which maintenance policy is one effect among several (Sherwin, 2000).

Bamber *et al.* (1999) evaluate the issues (research and case study) of TPM with reference to the problems affecting successful implementations within UK manufacturing. They also identify a common theme that runs through the many definitions and interpretations of TPM within manufacturing, in particular the difference in focus between Japanese and Western manufacturers. Essentially, the operational approach to TPM is consistent; it is only the focus that differs. The Japanese emphasis toward TPM is that of teamwork and small group activities working on a system of productive maintenance. The Western approach emphasises overall equipment effectiveness (OEE) through active participation of equipment operators, which moves the emphasis away from both maintenance and teamwork, towards equipment management and utilisation with operator participation.

The main issues identified by Bamber *et al.* (1999) as being detrimental to the successful implementation of TPM within the U.K were:

- 1 Simultaneous introduction of TPM on too many machines
- 2 Lack of involvement of production operators
- 3 Lack of sufficient training, skills, and experience
- 4 Lack of management support and understanding
- 5 The programme is too high level, run by managers, for managers.

Nonetheless, among observers such as Womack and Jones (1996), TPM is considered to be an indispensable contribution to lean production, supporting 'just-in-time' (JIT) manufacture and 'total quality management' (TQM). The issues of lean production, JIT, and TQM are discussed in more detail later in this chapter. However, within the context of different approaches to manufacturing and maintenance, the full use of TPM may be unfeasible. For example, operator involvement especially in hazardous or specialised areas of manufacture may be restricted due to health and safety and legal requirements.

2.4.7 Computers and information technology in maintenance

The use of enabling technologies, such as computers and information systems are already a fact-of-life for many maintenance departments. This is through the accessibility and portability of such technologies, and the growing trend for integration

with other areas of an organisation (Pintelon *et al.*, 1999; Starr and Ball, 2000). In a practical sense however, these techniques or methodologies can be considered only as indirect contributors to the overall effectiveness of the maintenance function.

Understandably, various types of information system have been developed, which use different techniques and approaches in order to suit the different styles or type of maintenance used by different companies. Such examples include ‘computerised maintenance management systems’ (CMMS), which are used to assist maintenance with issues such as planning, management and administrative procedures (Swanson, 1999), and ‘enterprise resource planning’ (ERP) systems, which are intended to standardise all departments within a company (including maintenance), by containing and sharing their collective resources (Koch *et al.*, 1999).

Additional examples would be the use of technology and technique specific ‘expert systems’ (ES), bespoke information systems that range from simple spreadsheet or database applications, to integrated ‘maintenance management information systems’ (MMIS), to ‘interactive electronic technical manuals’ (IETM), and digital maintenance manuals (Greenough, 1999; Davies and Greenough, 2000).

2.4.8 Maintenance management

Maintenance management is defined by British Standard BS381 (1993) as: “The organisation of maintenance within an agreed policy”. Blanchard (1995) refers to it as “the application of the appropriate planning, organisation and staffing, program implementation, and control methods to a maintenance activity”. A broad description of maintenance management is presented by Luxhoj *et al.* (1997) (Figure 2.4), which has twelve main fields grouped into three primary categories: technical, human, and economic. Maintenance, as a system in this example, is viewed as a “production system”, where maintenance services are considered as “products”.

Kelly (1997) discusses the primary tasks of the maintenance organisation and notes the considerable changes over the years, in which maintenance management in particular has been organised. Focussing on the resource (i.e., maintenance tradesmen and operators), and administrative (management) structure, Kelly maps development through case examples from the 1960s / 1970s up to present. Figure 2.5 illustrates how the trend in trade (resource) flexibility during this period has changed from heavily demarcated in the 1960s / 1970s, to that of maintainer operator in the 1990s. Considered more appropriate for the 1990s, with less management levels than previous, Figure 2.6

highlights the resource and administrative structure of maintenance possible within a medium to large size organisation. The resource structure of Nissan UK (Figure 2.7) supports this possibility, which in turn reflects the resource structure of Figure 2.6. The levels of management within Nissan are also similar to those presented in Figure 2.6.

The 12 main maintenance management fields

The technical part:

- **The maintenance “products”** - Specification of different types of services and “products” from the maintenance function. Specification in relation to each plant system.
- **Quality of the maintenance “products”** - Specification of quality of the maintenance jobs. Quality reports, certification documents, decisions about maintenance standards, etc.
- **Maintenance working methods** - Specification of working methods, time standards, relation between maintenance jobs, etc.
- **Maintenance resources** - Equipment for maintenance, buying maintenance services, information about new equipment, capacity of equipment, usage, controls, etc.
- **Maintenance materials** - Inventory planning, warehousing, relation to vendors, etc.
- **Controlling maintenance activities** - Scheduling of maintenance jobs, progress in work, manpower planning, etc.

The human part:

- **Internal relations in the maintenance function** - Relation to other departments, corporation and co-ordination, especially to production.
- **External relation to the maintenance function** - Relation to external parties, especially safety and environment, local authorities.
- **Organisation of the maintenance function** - Design of the organisation, selection of people, relation between groups of skills, responsibility and authority.

The economic part:

- **Structure of maintenance** - Work breakdown of maintenance, area structure, specification base (i.e., drawings).
- **Maintenance economy** - Economic control of maintenance, cost estimates, budgets, cash flow, accounting for maintenance, plant investment and financing.
- **Production economy** - Production economy versus maintenance economy, cost benefit of maintenance.

Figure 2.4 Main maintenance management fields (Luxhoj *et al.*, 1997)

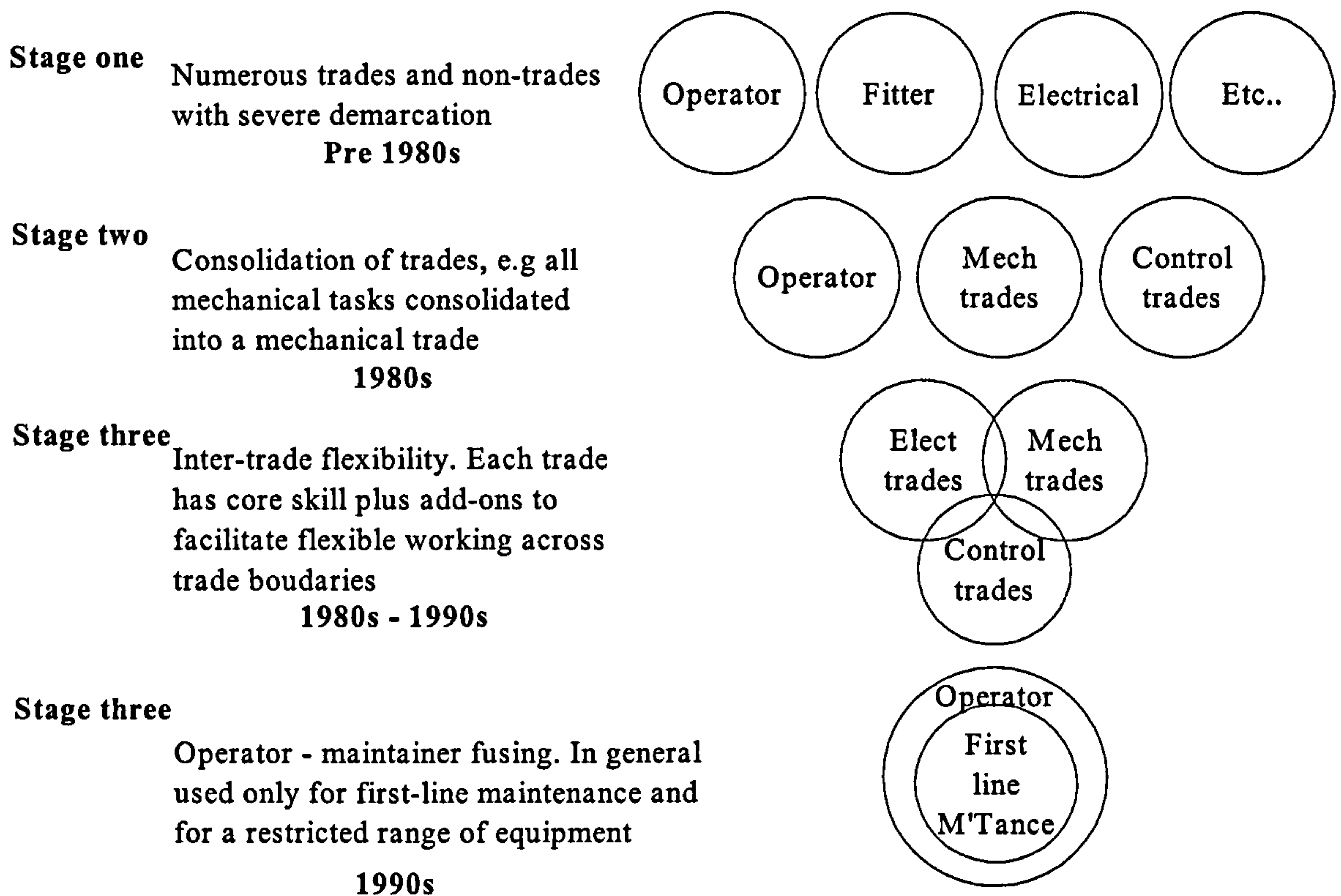


Figure 2.5 Change in tradeforce flexibility (Kelly, 1997)

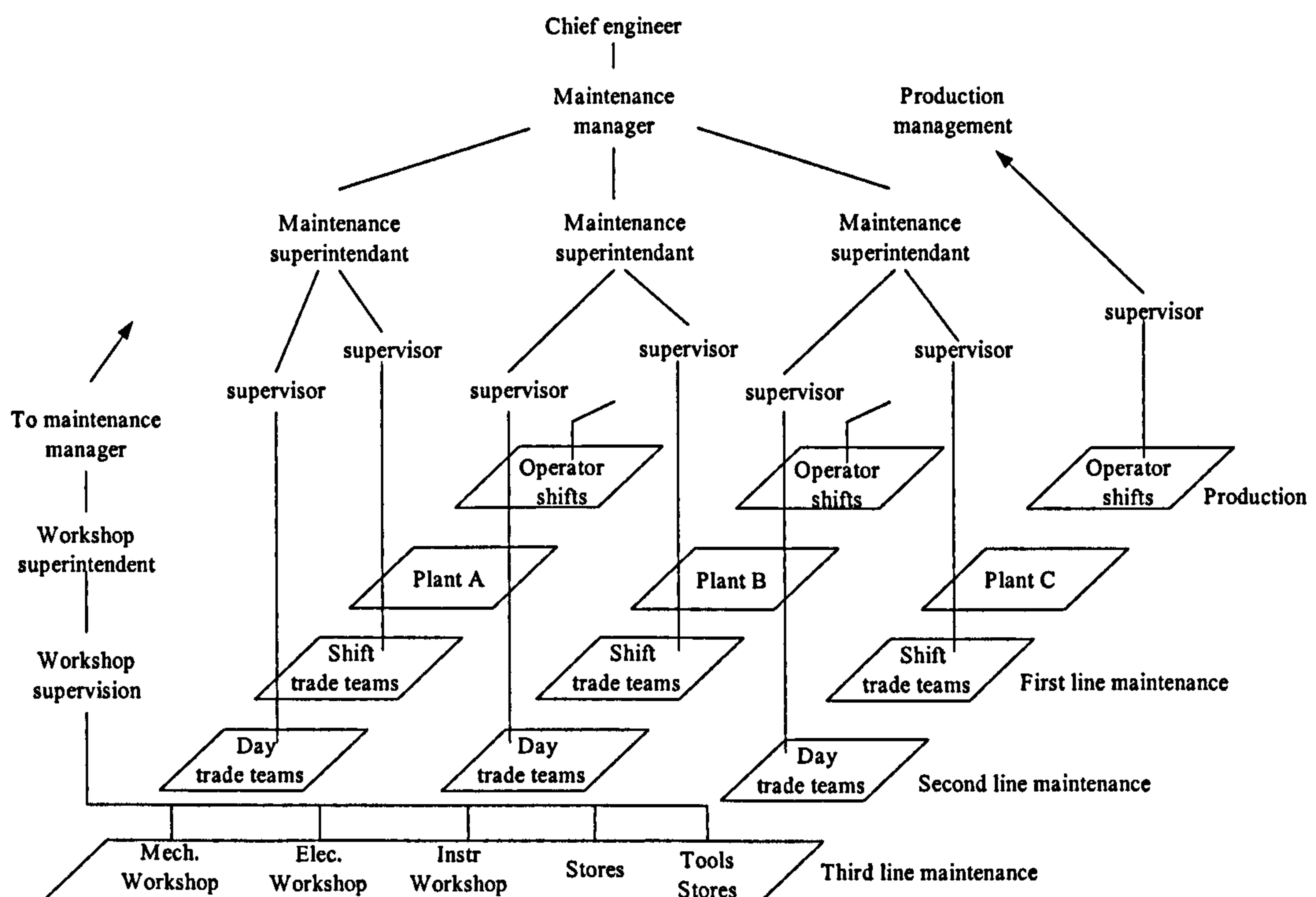


Figure 2.6 Resource and administrative structure within an organisation (Kelly, 1997)

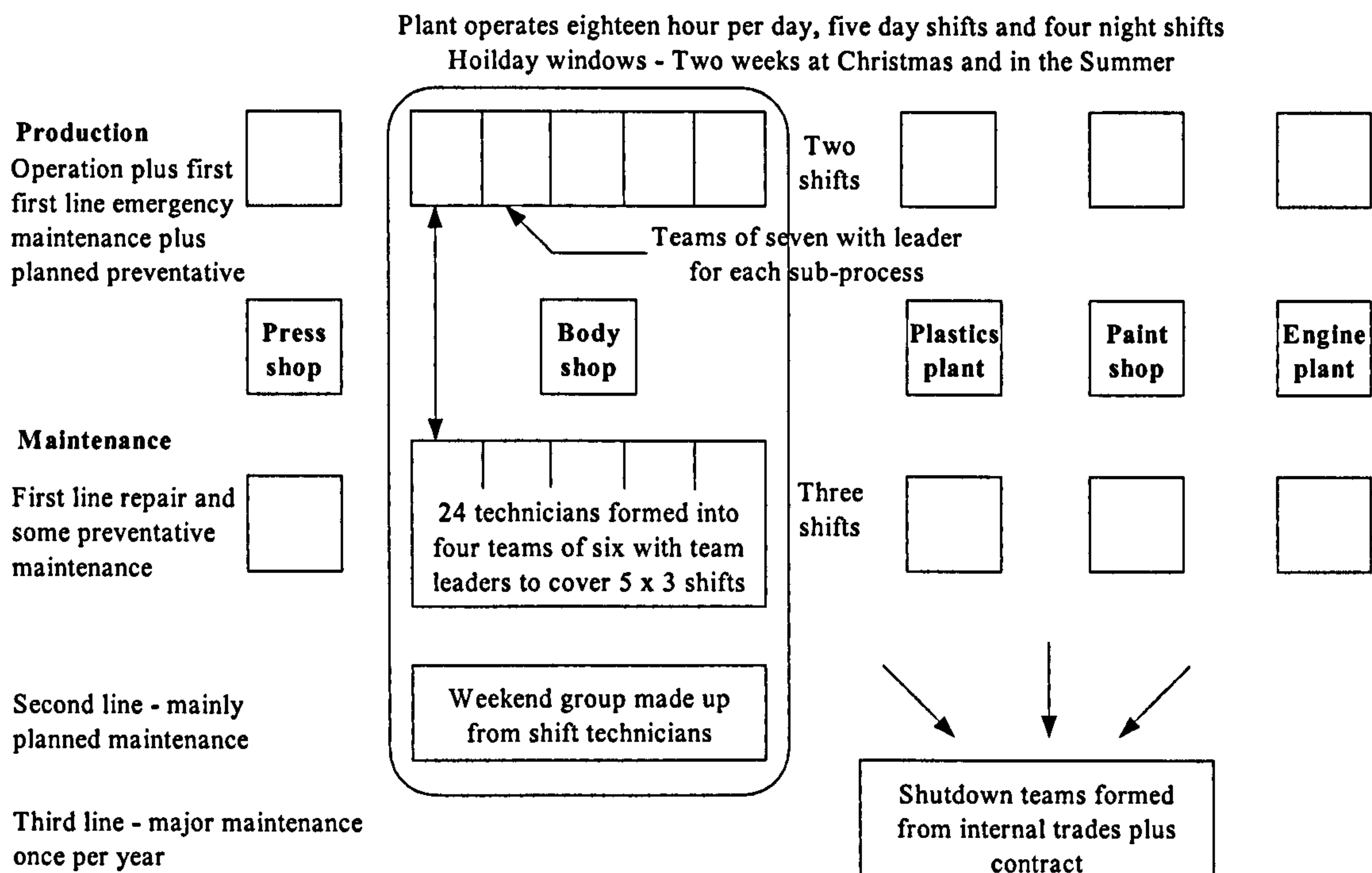


Figure 2.7 Resource structure, Nissan, U.K (Kelly, 1997)

Although examples of inter-trade flexibility and operator maintainer can be found, as demonstrated by Figure 2.7, development of such practice within the UK is not as widespread as it should be (Kelly, 1997). As Kelly points out, one reason for this is the high cost (in an environment of relatively high labour turnover) of the required training. Another major reason for the failure of maintenance management systems, is that the planning and supervising of functions are frequently mixed in an organisation, which creates confusion and leads to a reactive rather than proactive approach to maintenance (Wireman, 1990). Luxhoj *et al.* (1997) and Jonsson (1997) also highlighted issues concerning maintenance management; these issues are discussed below.

Research undertaken by Luxhoj *et al.* (1997) identified common trends between previous maintenance management investigations within the United States and Scandinavia. They used these trends to illustrate different approaches to maintenance management on an “as is” basis within Danish companies. Similarly, Jonsson (1997) investigated the state of maintenance management within a variety of Swedish manufacturers. However, although aspects of maintenance management such as RCM and TPM are commonly known and used, the researcher could reference no generic maintenance management model. For his survey research, Jonsson (1997) developed his own reference based on five linked components:

- 1 goals and strategy - that lead the organisation to fulfil corporate objectives
- 2 human aspects - the basis for company-wide commitment and continuous improvement
- 3 supporting mechanisms - communication and information
- 4 tools and techniques - used by maintenance
- 5 organisation - structure that determines resources

Nonetheless, although the scope of Luxhoj *et al.* and Jonsson's research may be considered by some as relevant only to Scandinavian industry, their findings and recommendations suggest a more universal approach to the issues of maintenance management. Some of their arguments are presented below:

- / 'With the trend to just-in-time (JIT) production, and flexible agile manufacturing, it is vital that maintenance management becomes integrated with corporate strategy to ensure equipment availability, quality products, on-time deliveries, and competitive pricing' (Luxhoj *et al.* 1997) ✓
- / 'The changing needs of modern manufacturing necessitate a re-examination of the role that improved maintenance management plays in achieving key cost and service advantages' (Luxhoj *et al.* 1997)
- / 'There is a need to develop clear maintenance objectives and goals, to define key variables for measuring and controlling maintenance activities, to ensure better linkages between maintenance and production, to focus on organisational issues' (Luxhoj *et al.* 1997)
- / 'Maintenance systems have poor links to corporate strategy, which leads to a deterioration of formal systems, due to lack of meaningful reinforcement' (Luxhoj *et al.* 1997)
- / 'The importance of viewing maintenance as a company-wide approach is obvious' (Jonsson, 1997)
- / 'Many companies do not have clear goals for manufacturing, and even fewer have any for maintenance. This is serious, as strategies and goals are prerequisites for achieving more effective maintenance' (Jonsson, 1997)
- / 'The optimum maintenance organisation structure is dependent on the specific conditions within the organisation. Participation of maintenance workers in project

teams, focusing on the core business are important organisational trends' (Jonsson, 1997)

- / 'Most of the maintenance management components can probably be improved. It is necessary to formulate clear maintenance strategies that are linked to manufacturing and corporate strategies' (Jonsson, 1997).

2.4.9 Maintenance costs

The British Standard Institute define maintenance cost as: "The total cost of retaining an item in, or restoring it to, a state in which it can perform its required function" (BS3811, 1993). In practice, the language of higher management is money, and so the costs and values of maintenance to the company should be expressed in cash terms as part of the system of management (Sherwin, 2000).

An investigation by the Ministry of Technology (U.K) in 1968, reported the first assessment of overall U.K direct maintenance costs, which at that time were estimated at £1.1 billion. It was suggested that if maintenance staff productivity could be improved, then costs could be reduced by 40%, in effect saving £300 million in lost production (van Rijn and Scholten, 1996). By 1990, Wireman had observed that since 1979, maintenance costs for industrial firms in the United States had risen by 10-15% per year. In 1990, the total in excessive maintenance expenditures was approximately 200 billion dollars, which incidentally equalled the total maintenance costs in 1979.

In 1991, a Department of Trade and Industry report (DTI, 1991; reprint, 1996) showed that with good maintenance management, the 3.7% of annual sales value spent on maintaining direct production assets could be reduced by as much as 8% within the U.K. Simultaneously, plant availability could be improved to the extent that a 30% increase in profitability would not be unrealistic. The emphasis of this report, as with the earlier 1968 report, was to encourage a better maintenance management approach. Although in 1994 as Luxhoj *et al.* (1997) note, instances of 8-12.5% annual maintenance costs, as a percentage of total equipment costs for certain industries, were evident.

The importance of cost control over the life cycle of products, processes, or systems are also important issues that concern maintenance (Luxhoj *et al.*, 1997). The current British Standard definition of 'life cycle cost' (LCC) is: "The total cost of ownership of an item, taking into account all the costs of acquisition, personnel training, operation, maintenance, modification and disposal" (BS3811, 1993). Coincidentally, this definition (not dissimilar to Husband's cited definition of 1976), is similar to the goal of

TPM, which aims to maximise equipment effectiveness (Nakajima, 1988). However, a recent U.K survey of maintenance managers (Benchmark Research, 2000), found that the majority of those canvassed (73%) did not carry out life-cycle costing, despite the perception that those who conducted LCC were more effective departmentally than those that did not.

2.4.10 World class maintenance

World class maintenance, rather than being consciously developed, has arisen through a process of evolution (Idhammar, 1992). As such, in terms of the definition of maintenance, and maintenance management in particular (e.g., BS3811, 1993), it cannot be regarded as a distinct maintenance policy. However, world class maintenance may be explained in the same context as world class manufacturing. World class manufacturing is an umbrella term for a variety of forms of work organisation; managerial and manufacturing techniques; processes and systems, which improve the capacity for increasing the flexibility of an enterprise (Haynes, 1999).

2.4.11 Summary of maintenance and maintenance in manufacturing

The definition of maintenance, its various forms, and how they relate to manufacturing has been introduced and discussed by the researcher. Within the discussion, the British Standard definition of maintenance and maintenance management was used as an impartial reference. The focus of learning also sought to understand core and commonly understood features and approaches to maintenance, its practice, management, and cost issues. The historical contribution and use of such techniques and approaches such as RCM, Terotechnology, TPM, computers, and information technology were included to highlight the practice of maintenance. Management issues in terms of resources structure (i.e., manpower and administration) and effects of policy and practice were covered in this section, as was the importance of understanding how maintenance effectiveness can contribute, or be affected by the issue of cost.

Essentially, the theme of this section has been to highlight the principal responsibility of maintenance: to provide a service to an organisation, enhancing its ability to make a profit. The literature so far, suggests that a more integrated approach to maintenance could improve an organisations ability to operate and compete effectively. Failing to do this could lead to a deterioration of formal systems through lack of meaningful reinforcement, seriously affecting the ability of those organisations to make a profit.

The effectiveness of the maintenance function is a major management and technical issue through increased demand on productivity, quality, and availability. However, different companies, with different management approaches formulate their own opinion of how the definition of maintenance should be applied within their own organisations. Throughout this research, allowance has been made concerning definition and policy flexibility of practitioners and commentators regarding maintenance. Similarly, although aspects of maintenance management such as RCM and TPM are commonly understood and used, no generic maintenance management model could be referenced.

2.5 Towards lean

This section discusses the issues of lean thinking, lean production, lean enterprise and their features. It provides an introduction to lean production, lean thinking, and lean enterprise, and then discusses each separately within the context of their characteristics and associated methodologies. Contributions to the organisation are also discussed.

2.5.1 Introduction to lean production, lean thinking and lean enterprise

The concept of lean thinking (Womack and Jones, 1996) originated from the Toyota production system (TPS), developed in 1950s Japan (Katayama and Bennett, 1996), through the lean principles described by Womack *et al.* (1990). The industries not influenced by the principles and demonstrated benefits of lean, along with its associated methodologies such as just-in-time (JIT), total quality management (TQM) and total productive maintenance (TPM), are becoming fewer (Katayama and Bennett, 1996). A brief summary of the central theme, principles and characteristics of lean thinking, which among other features refer to the total enterprise (Womack *et al.* 1990; Womack and Jones, 1996; Bicheno, 2000), is summarised by Bicheno (2000) and has been developed further as below in Figure 2.8.

Comm and Mathaisel (2000) state that “Industries strive for leanness, because being lean means being competitive by eliminating the non-value added practices”, i.e., wastes. However, the strategy for a generic lean practice implementation, and achieving leanness throughout, lacks strong evidence and is not clear to many (Comm and Mathaisel, 2000; Chang, 2001).

Central theme of lean thinking

Eliminate waste

The five lean principles

<u>Specify value</u> Suit the needs from a customer point of view(vision). Internal / external	<u>Identify the value stream</u> Identify the sequence of processes from product concept to market	<u>Make value flow</u> One piece production flow. Never delay a value adding step by a non-value adding step.	<u>Pull</u> Only make as needed.	<u>Perfection</u> What the customer wants, at the right quality, time, price and without waste.
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The fifteen characteristics of lean

<u>Customer</u> Understand the true demand (internal /external)	<u>Simplicity</u> In operation, technology & process	<u>Visibility</u> Operational visibility & transparency	<u>Regularity</u> No surprise operations, "time pacing"	<u>Synchronisation</u> Keep it moving. Seek flow	<u>Pull</u> Work at customers rate of demand
<u>Waste</u> Learn to recognise then reduce	<u>Process</u> Think horizontal & map to understand process	<u>Prevention</u> Shift emphasis from failure to prevention	<u>Time</u> Simultaneous & parallel operations. Time as a measure	<u>Improvement</u> Beyond waste reduction to include innovation	
<u>Partnership</u> Seek to build trust, with supplier and customer	<u>Gemba</u> Innovation in the workplace not in the office	<u>Variation</u> Seek to reduce. Understand the limits	<u>Participation</u> Everybody takes responsibility! Everything shared		

Figure 2.8 Theme, principles and characteristics of lean thinking: after Bicheno (2000)

2.5.2 Lean production

The concept of lean production does not refer to the issues of what production systems are, especially in the sense of Black's definition discussed in part 2.3.1. ✓ Lean production reflects ways of thinking about production, the assumptions that underline how people and institutions formulate solutions to the problems of organising people, equipment, material and capital, to create and deliver products for customers (Liker, 1998). ✓

The term "lean production" was coined in 1990, and was used to recognise and categorise the unique system of manufacturing pioneered by Taiichi Ohno within Toyota:

"Lean production... is 'lean' because it uses less of everything compared with mass production - half the human effort in the factory, half the manufacturing space, half the investment in tools, and half the engineering hours to develop a

new product in half the time. Also, it requires keeping far less than half the needed inventory on site, results in many fewer defects, and produces a greater and ever growing variety of products” (Womack *et al.* 1990).

It is from this paradigm that production systems emerge, so lean exemplifiers such as the Toyota production system (TPS) and others, e.g. the Ford production system (FPS), are nothing more or less than a set of solutions to achieve the “lean” ideal (Liker, ed., 1998).

The essence of lean production is based on three core features: JIT, TQM and TPM. Incidentally, the use and management of these and other lean features within manufacturing is typically referred to as lean manufacturing (Liker, ed., 1998; EEF, 2001). These three core features are introduced and discussed in general terms as follows.

2.5.3 Just in time (JIT)

The basis of the Toyota production system is the absolute elimination of waste (discussed previously), and attaining smooth production flow in the face of a varied product mix. Ohno (1988) described the system evolved and used at Toyota as resting on two pillars: just in time and ‘autonomation’, or automation with a human touch

JIT is an approach to improving overall productivity and eliminating waste, in particular, overproduction. It controls cost effective production and delivery of the right parts where they are needed, at the right quality, at the right time and place, while using a minimum amount of facilities, equipment and resources (i.e., people). To realise JIT, a method of control and communication known as ‘Kanbans’ is used. Kanbans are used to pick up information, transfer information, and provide production information.

The other pillar of the Toyota production system, autonomation refers to machines that are both automated, so that one worker can operate many machines, and foolproofed, so that they can automatically detect problems. Ohno considered automation as an important factor for improved productivity, as such ‘foolproofing’ (i.e., Pokayoke) was developed to help operators intervene in an automated process at the right time (i.e., automation with a human touch). He viewed this combination as necessary to avoid disruptions in a JIT environment.

2.5.4 Total quality management (TQM)

Oakland (1995) states that TQM “is an approach to improving the competitiveness, effectiveness and flexibility of a whole organisation”. As such, TQM works very well with JIT, and used together are considered essential features of lean production. Nonetheless, although many definitions exist, the principles of TQM are essentially the same. Schonberger in 1983, summarised seven principles observed as essential to the quality practice success of the Japanese:

- 1 Process control – The use of statistical methods for process control and worker responsibility, for quality and authority, to make changes when needed
- 2 Easy-to-see quality – The extensive use of visual displays of quality measures, gauges, meters, and recognition awards to put quality on display and more visible
- 3 Insistence on compliance – Quality first, output second, at every level in the system
- 4 Line stop – The quality first principle, giving authority to line workers to stop the line to correct quality problems (e.g., defect prevention, not discovery)
- 5 Correcting one’s own errors – Requirement of groups or individuals that produce a defective item to fix it
- 6 The 100 percent check – Ongoing inspection, not just random checks. Simple or automated inspection techniques such as foolproofing
- 7 Continual improvement – Seek out zero defects as a target.

Another fundamental aspect of total quality, used by Toyota and viewed as a lean cornerstone, is good housekeeping (Bicheno, 2000). Good housekeeping aims to make standardised operations the norm and is referred to as the 5S or CANDO concept: 5S to mean, sort, straighten, shine, systemise, sustain; CANDO to mean, clean, arrange, normalise, discipline, and ongoing (improvement), (Bicheno, 2000).

2.5.5 Total productive maintenance (TPM)

As introduced earlier in part 2.4.6, TPM was developed and implemented in Japan by Seiichi Nakajima in 1971 (Nakajima, 1988). As Nakajima states, “It is safe to say that without TPM, the Toyota production system could not function”. As a characteristic of lean production, TPM is aimed at zero breakdowns and zero defects, which deviates from the specialist maintenance function to improve global consideration, i.e., the operator, the process, and environment (Nakajima, 1988). Figure 2.9 illustrates the relationship between TPM and the principle features of the Toyota production system:

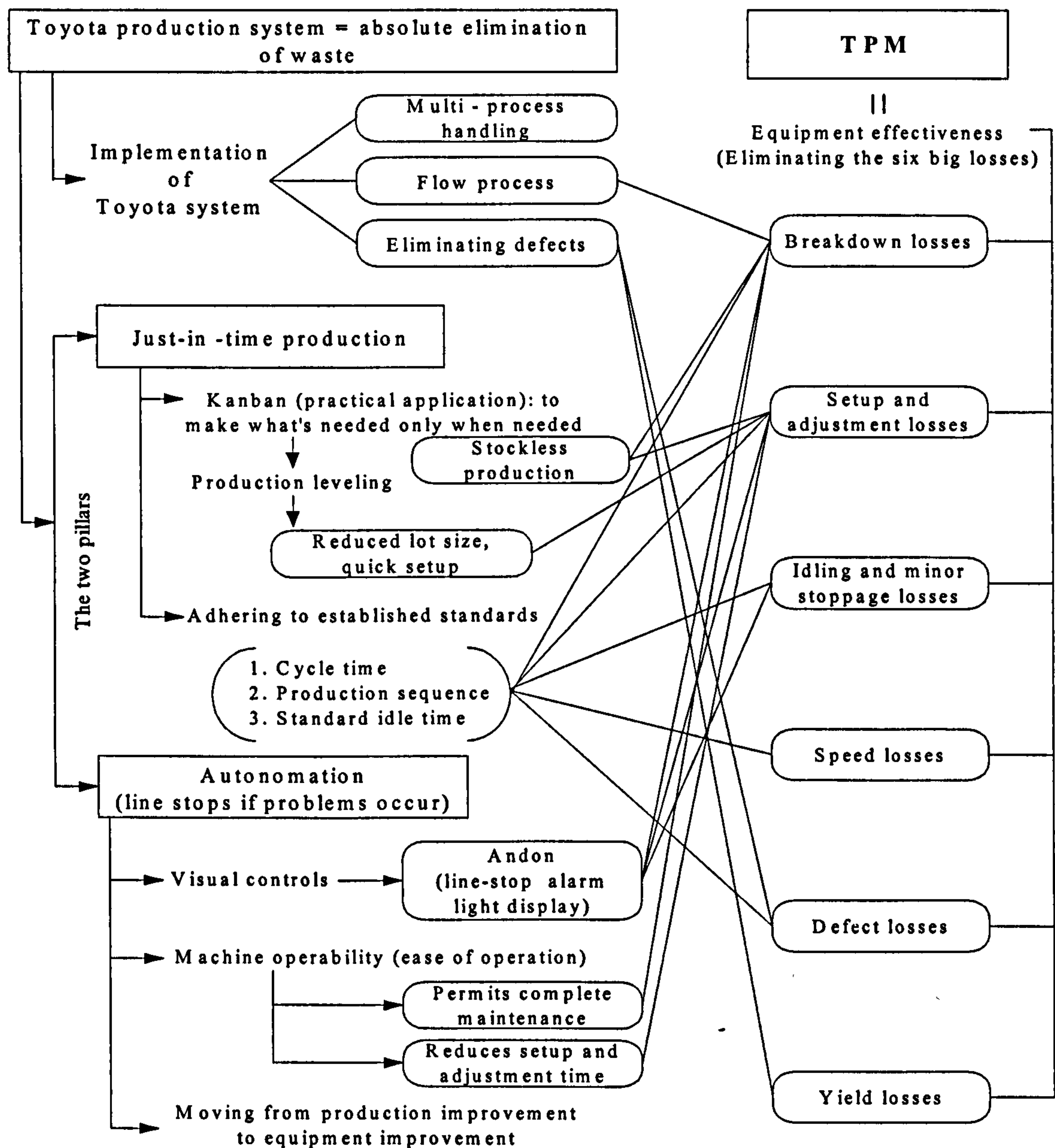


Figure 2.9 Toyota production system and TPM (Nakajima, 1988)

In common with TQM, JIT, and 'total employee involvement' (TEI) within lean production, TPM through continuous improvement, aims to make maintenance problems visible (JIT management, by fact approach), and through prevention not reaction (e.g., TQM prevention, not detection approach). Figure 2.10 provides a representation of how TPM fits into an organisation, and how the administrative and resource structure is disseminated and promoted. Also noticeable in Figure 2.10, are the similarities in the administration and resource structure of TPM promotion to the structures presented previously in Figures 2.6 and 2.7:

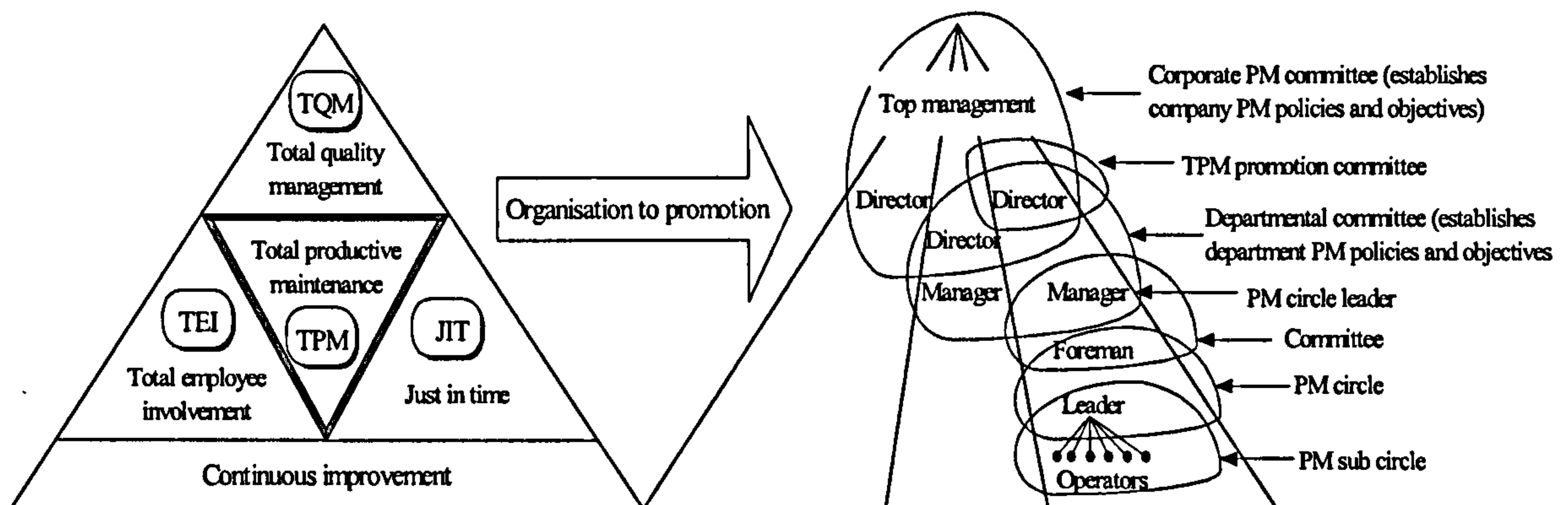


Figure 2.10 From the organisation to its promotion, a view of TPM
(from DeWeese, 1999; Kelly 1997)

The most visible connection between TPM, JIT, TQM, and TEI within lean production is the use of OEE. Presented within context to the Toyota production system in Figure 2.9, OEE is seen as a way to manage and overcome the six big losses, address machine availability problems, and improve quality. Figure 2.11 highlights how OEE is related to equipment effectiveness, the six losses, and how it is calculated. For a typically lean production environment, an ideal OEE for profitable TPM should be at least 85% (Nakajima, 1988).

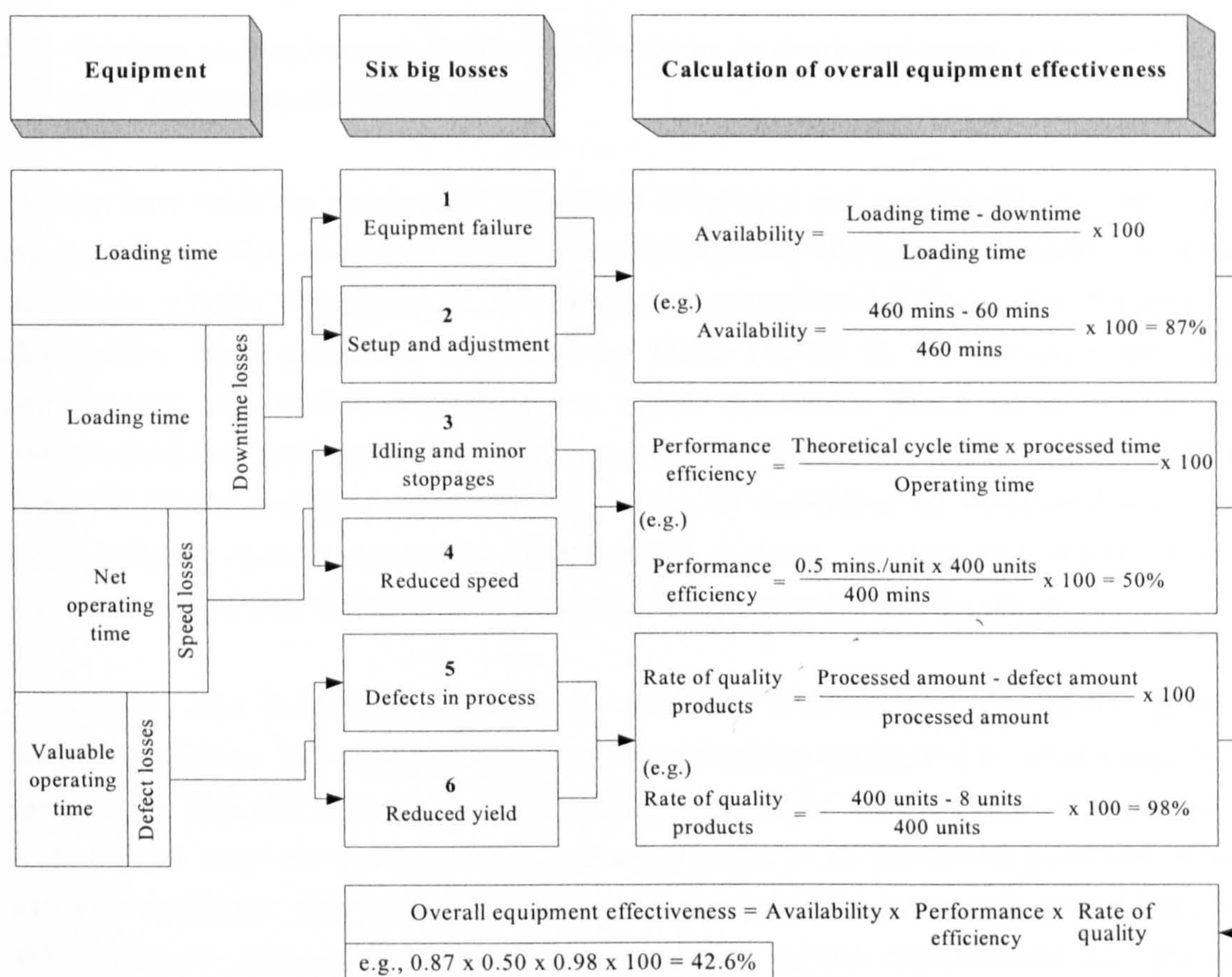


Figure 2.11 Overall equipment effectiveness example (Nakajima, 1988)

2.5.6 Lean thinking

In 1984, the international motor vehicle program at the Massachusetts Institute of Technology began its now famous five year, five million dollar study of the world automotive industry. The findings of this study summarised by Womack, Jones and Roos in 1990, turned out to be a highly useful and popular synthesis of advanced manufacturing practices at that time. Six years later in their book ‘Lean Thinking’, Womack and Jones (1996b) renewed their message to extend it beyond the automotive industry. The basis of their contribution was to develop a set of principles as an antidote to the wastes present within organisations; this antidote that was consequently termed “lean thinking”. The theme, principles and characteristics of lean thinking were previously presented in Figure 2.8 to which Womack and Jones add that it:

“Provides a way to specify value, line up value-creating actions in the best sequence, conduct these activities without interruption whenever someone requests them, and perform them more and more effectively. In short, lean

thinking is lean because it provides a way to do more and more, with less and less” (Womack and Jones, 1996b).

From a lean thinking perspective, improved efficiency and profitability can be sought by increasing value within an organisation through the elimination of waste (Womack and Jones, 1996b; Womack *et al.*, 1990). The wastes referred to here and in the previous description, were previously identified by Ohno (1988) as the activities within an organisation that absorb resources, but create no value. These seven wastes are: overproduction; waiting; transporting; processing; inventory; motions; and defects. Bicheno (2000) complemented Ohno’s wastes by providing an additional seven for consideration: human potential; inappropriate systems; energy and water; wasted material; service and office wastes; customer time; and customer defection.

Essentially, lean thinking is a philosophy based on Womack and Jones’s five guiding principles (Figure 2.8) and their subsequent requirement captures (i.e., what needs to be looked at). The aim is a “comprehensive business logic” that provides manufacturing with logical ways of waste analysis, pursuing value to its maximum potential, which includes customers and suppliers, that provide opportunities to rethink overall benefits. What is more difficult however, is the translation of the requirements into product characteristics, e.g. “applying these five concepts requires a complete organisational transformation, and it’s difficult for the uninitiated to know where to start” (Womack and Jones, 1996a).

✱ 2.5.7 Lean enterprise

✓ Going beyond their experience of the Toyota production system, Womack and Jones (1994) extended the notion of applying lean techniques to discrete activities to include internal and external customers and suppliers. By way of explanation, ‘internal’ refers to bridging the communication and activity gap between departments and workers, ‘external’ means extending beyond one single company, and bridging the gap between themselves and all their customers and suppliers within a product or service (value) chain. To explain this, they coined the phrase “lean enterprise”. Their vision of a lean enterprise is, “A group of individuals, functions, and legally separate but operationally synchronised companies” (Womack and Jones, 1994).

2.5.8 Summary of lean production, lean thinking and lean enterprise

At face value, it is difficult to disseminate what lean thinking, lean production, its associated terminology (i.e., lean manufacturing) and lean enterprise are. A casual observer may see no perceived difference. However, acknowledging that lean is a philosophy that consists of many concepts, the following differences are highlighted:

- 1 Lean thinking is organisational (i.e., company based), it emphasises the importance of a comprehensive business logic that provides manufacturing with logical ideas of waste analysis
- 2 Lean production or manufacturing, is a function of production, it aims to improve the processes involved with manufacturing through technology, process, techniques, management, and control
- 3 Lean enterprise goes beyond the boundary of lean thinking, from the organisation to intra-company relationships that focus on improving the value chain, to effectively link manufacturing activities, and deliver product value.

2.5.9 Lean practices and tools

Throughout literature, and indeed practice, it is clear that many tools, techniques, approaches and concepts exist that help organisations to become lean, or for that matter leaner, e.g. 'The lean toolbox', Bicheno (2000), Toyota production system, etc. What is not clear, is that a generic and fully understandable lean practice implementation to achieve leanness throughout exists (Comm and Mathaisel, 2000; Chang, 2001). This is not to say that efforts have not been made as they have, but these have generally focused more on production and the business process than other issues (Chang, 2001). To highlight this argument the following examples are used.

Monden (1994), felt that to achieve standard operation through continuous improvement, 5S housekeeping needed to be implemented first, followed by factory layout improvements, machine setup reduction, multi-function training, and production smoothing. Shingo (1989) on the other hand, focuses on improved product flow through the reduction of overproduction waste. His focus was to implement set-up reduction then apply mistake proofing (e.g. foolproofing), followed by multi-function training, lot size reduction, level production, and pull production control. Womack and Jones (1996a; 1996b), go beyond Monden and Shingo's focus on production. They include the business process and suggest that the entire value stream should be mapped to

differentiate waste, seek customer pull to minimise further waste, then work on product balancing for the next stage

Comm and Mathaisel (2000) recognise that lean is composed of a number of links, but also that the strategy for achieving lean is not clear to many. To be successful at implementing lean concepts therefore, it is important to identify the links and engage each link in a process. By identifying the process, a strategy can be developed for implementing lean principles and practices. Similarly in the book “Becoming lean: Inside story of U.S manufacturers” edited by Liker (1998), the basis for lean implementations in the case reviews were based on the internal needs of the companies and external requirements of the customers.

2.5.10 Lean and the organisation

Many companies have adopted the various aspects of lean manufacturing developed by Toyota. However, the question posed by Steven Rasch (Liker, 1998) was: “Do the core practices of lean manufacturing really make a difference to performance?” To answer this, Rasch conducted empirical research, based on a survey of 249 companies from three industries (metal forming, plastics processing, and machine tooling). The purpose of the survey was to compare industrial practices of companies and track changes over a period of time. The survey was divided into six sections that addressed general business issues, design, procurement, shop scheduling, manufacturing practices, and quality management. The outcome of his research suggested that yes, lean practices do make a difference and that overall lean manufacturing practices led to better performance. Additionally, he suggested there was a strong interaction between the technical features of lean manufacturing (i.e. JIT and preventative maintenance) and the involvement of production workers.

More recently in December 2001, a report on current U.S and U.K manufacturing productivity across a range of industries was published by the engineering employers federation (EEF, 2001), which included the organisational impact of lean manufacturing. The interim report showed that U.K manufacturers have some way to go before they fully embrace lean manufacturing. Of the companies interviewed, over 30% were applying lean across their organisation, 12% in manufacturing only, and 40% not at all.

For the companies pursuing lean manufacturing, the primary motivation for 70% was to boost overall company performance in terms of increased efficiency, productivity,

profitability, and lower costs - customer pressure accounted for 15%. Of the companies who have implemented lean, over 90% say that it has been quite successful. It is also the larger firms who see most success. The research also found that those companies using four or more key lean tools tended to have the largest increase in productivity and profitability. The average productivity increase of those using four or more lean tools was 11%, whereas those who did not ran at about 7%.

2.5.11 Towards lean; a summary

In 1990, the lean production concept based on Toyota's coherent approach to manufacturing was viewed by Womack *et al.* as an alternative to traditional manufacturing approaches. This powerful advertisement of Toyota's competence and manufacturing leadership appealed to researchers, industrial engineers, and consultants alike, as a way to seek a systematic explanation for their success through articles, books and industrial examples. As such, its influence can be found in a wide range of manufacturing and service industries.

Presented as a paradigm for the future in 1990, the principles of the Toyota production system are still referenced as contributors to the use of improved lean concept use. Three recognisable yet different approaches have been discussed in their present day context: lean thinking, lean production (e.g., lean manufacturing) and lean enterprise. Implementations for these approaches generally are not generic, which also applies to the tools and techniques available to become lean. The common theme is that the type of lean approach and tools used depend largely on the internal needs of the companies and external requirements of their customers. Nonetheless, the use of lean techniques and approaches have allowed companies to boost profitability, through improved performance and efficiency at a lower cost, providing productivity improvements for users by as much as 11% overall (EEF, 2001).

2.6 Lean and the maintenance issue

As discussed previously, lean concept use has been shown to increase the effectiveness and profitability of an organisation through the elimination of waste (EEF 2001). Similarly in 1991, the DTI emphasised that good maintenance practice could also contribute to the increased profitability of an organisation. By 2002, information was not evident for the researcher to suggest otherwise. In fact, a recurring theme within literature suggests that a more integrated approach to maintenance within an organisation could still improve its ability to operate and contribute effectively.

TPM has been introduced as a characteristic of maintenance and lean, and is considered an important contributor to any organisation who practices it. However, it is only one part of the actions, processes, techniques, and methodologies associated with either maintenance, lean, or in the case of a lean manufacturer, both. That TPM contributes either directly or indirectly to the effectiveness and productivity of an organisation highlights the mutuality of both maintenance and aspects of lean. The question now is can lean concepts be used in conjunction with maintenance, through some form of combined activity that may benefit an organisation, or even just maintenance? If so, are they already being used and are they effective?

Research has shown that other lean thinking approaches and techniques, not just TPM, are used by maintenance to support their activities (Davies and Greenough, 2001). However, this research could not identify a strategy for a generic lean practice implementation, or comprehensive list of lean activities used by maintenance. Although the findings showed that greater recognition and use of lean thinking concepts within maintenance are needed, those that use lean concepts still considered them “good” or “fairly good” approaches to use.

As discussed previously, many tools, techniques, approaches, and concepts exist that help organisations to become lean, or leaner. However, for the reasons previously explained it is unlikely that a lean reference framework for maintenance generally would exist that could identify appropriate lean concepts, or explain possible benefits. As such, continued research needs to be undertaken to investigate the level of presence of lean thinking within the maintenance domain, and its influence and interaction with the maintenance function. The survey research by Davies and Greenough (2001) discussed earlier was useful in providing an initial insight into the presence of lean approaches, techniques, and concepts used to assist the maintenance function, but can not go far enough for more in-depth research. Therefore, research other than survey would be needed if more explanatory information were required, i.e. case study investigation.

Case studies allow investigations to retain the holistic and meaningful characteristics of real-life events. They can be either descriptive, explanatory or explorative strategies conditioned by the type of research question posed, the extent of control the researcher has, and the degree of focus on contemporary as opposed to historical events (Yin, 1988). Put simply, case studies are preferable when ‘how’ or ‘why’ questions are needed, and when the investigator has little control over the events being investigated.

/ In case study research, both qualitative and quantitative methods of information can be used to understand situations under investigation. Qualitative analysis, through interviews, semi-structured or otherwise, as well as observation helps to determine the level of practical use and perceived usefulness of the issues under investigation. Quantitative analysis seeks to provide meaningful information from raw data retrieved from sources. The translation of quantitative data to support the research may be achieved through the use of performance measures. /

2.6.1 Performance measurement

Performance measurement is the process of quantifying action, and can be defined as measuring the efficiency and effectiveness of action (Neely *et al.*, 1994; Neely *et al.*, 1995). Overall, the use of performance measurements and their strategic importance to organisations have been well-documented (Kaplan and Norton, 1992). On a more essential level, efficiency and effectiveness measurements focus on the central issues of the business which are usually cost, quality, delivery, people, suppliers, markets and new product introduction (Bicheno, 2000; Kaplan and Norton, 1992; 1996). However, beyond academic interest a lack of research into the practical implementation and use of performance measurement systems has been noted (Bourne *et al.*, 2000).

2.6.2 Maintenance performance measurement

To measure the effectiveness of the maintenance function, performance measurements should reflect all relevant factors that affect performance (Niebel, 1994; Armitage, 1970). Stated simply, any choice of action concerning performance measurement generally and within maintenance should fulfil at least two fundamental criteria. These are that all actions should be viewed in relation to the organisation, and should satisfy the requirements of the decision-maker (Neely *et al.*, 1994; Neely *et al.*, 1995; Bourne *et al.*, 2000; Niebel, 1994; Armitage, 1970).

Various index and quality-based methods for measuring maintenance performance and for controlling maintenance effort have been developed ((Kutucuoglu, 2001; Jardine, 1970). Measures regarding various lean activities have also been developed (Kutucuoglu, 2001; Nakajima, 1988; Dal *et al.*, 2000). However, it has been suggested that these measures, although beneficial as monitors, are either not suitable as sole performance measures or require further research (Kutucuoglu, 2001; Dal *et al.*, 2000).

2.7 Summary of literature review

The concept and use of lean thinking is aimed at adding value to an organisation through the elimination of waste. The maintenance function is expected to add value through its activities, requiring greater management integration within the enterprise. However, despite some methodologies associated with lean thinking being used by maintenance, evidence could not be found by the researcher to support a generic structure for lean activities. Furthermore, there is no evidence that suggests a suitable methodology that can identify possible improvements for the maintenance function of lean thinking activities, other than direct operational measures.

It is evident from the literature, research, and management perspective that the maintenance function would benefit from a lean approach to align with business objectives. As a contributor towards an organisation's profit, there is a need for maintenance to improve efficiency. These elements are fundamental characteristics of lean thinking and are implemented using TPM and other approaches to support maintenance activities. The added need by management to measure improvement, through use of these and other techniques, calls for a strategy of generic lean practice implementation and performance measurement.

This research has shown there is little evidence of a defined order of lean practice, or a comprehensive list of lean activities used by maintenance. As no clearly defined lean practice framework can be referred to, a comprehensive template to represent lean activities possible within a company, in particular the maintenance function needs to be developed.

2.8 Development of research question and hypothesis

Throughout this chapter, standard definitions have been used as an impartial reference where possible. As such, a research question needs to be presented for further investigation and suitability, representative of the issues discussed without bias, or loss of interpretation. One such question, based on an earlier query for preliminary research by Davies and Greenough (2001), may be presented that will form the basis of a suitable methodology for further investigation:

“How does lean thinking improve the effectiveness of the maintenance function?”

A proposed hypothesis therefore, may now be used as a basis for further investigation:

“Lean thinking improves the effectiveness of the maintenance function”.

Based on the strategies available (survey and case study), the following chapter presents and discusses the research methodologies suitable to address the research question through the hypothesis, and develop a fuller understanding of the subject area for this research.

2.8 Chapter summary

This chapter has highlighted and discussed the combined issues of manufacturing systems, maintenance, lean production, lean thinking, lean enterprise and measures of performance through examination of their related practical and research issues, views and concepts. However, this research could not identify a strategy for a generic lean practice implementation, or a comprehensive list of lean activities either previously or currently used by maintenance. Additionally, the researcher has shown that greater recognition and use of lean thinking concepts within maintenance, to support the manufacturing process are needed. Using standard definitions where possible, impartiality was sought throughout to explain all the issues within context of each other, in particular for the formation of a suitable research question and hypothesis to enable continued research.

Chapter Three

Research methodology

3.1 Introduction

The purpose of this chapter is to show the development of an appropriate method of research, based on the issues discussed within the literature review. In addition, a suitable research methodology will be described. Consideration is given to the broader issue of a research strategy before description of an appropriate research methodology to meet the research aim. Figure 3.1 provides a schematic representation of the structure of this chapter:

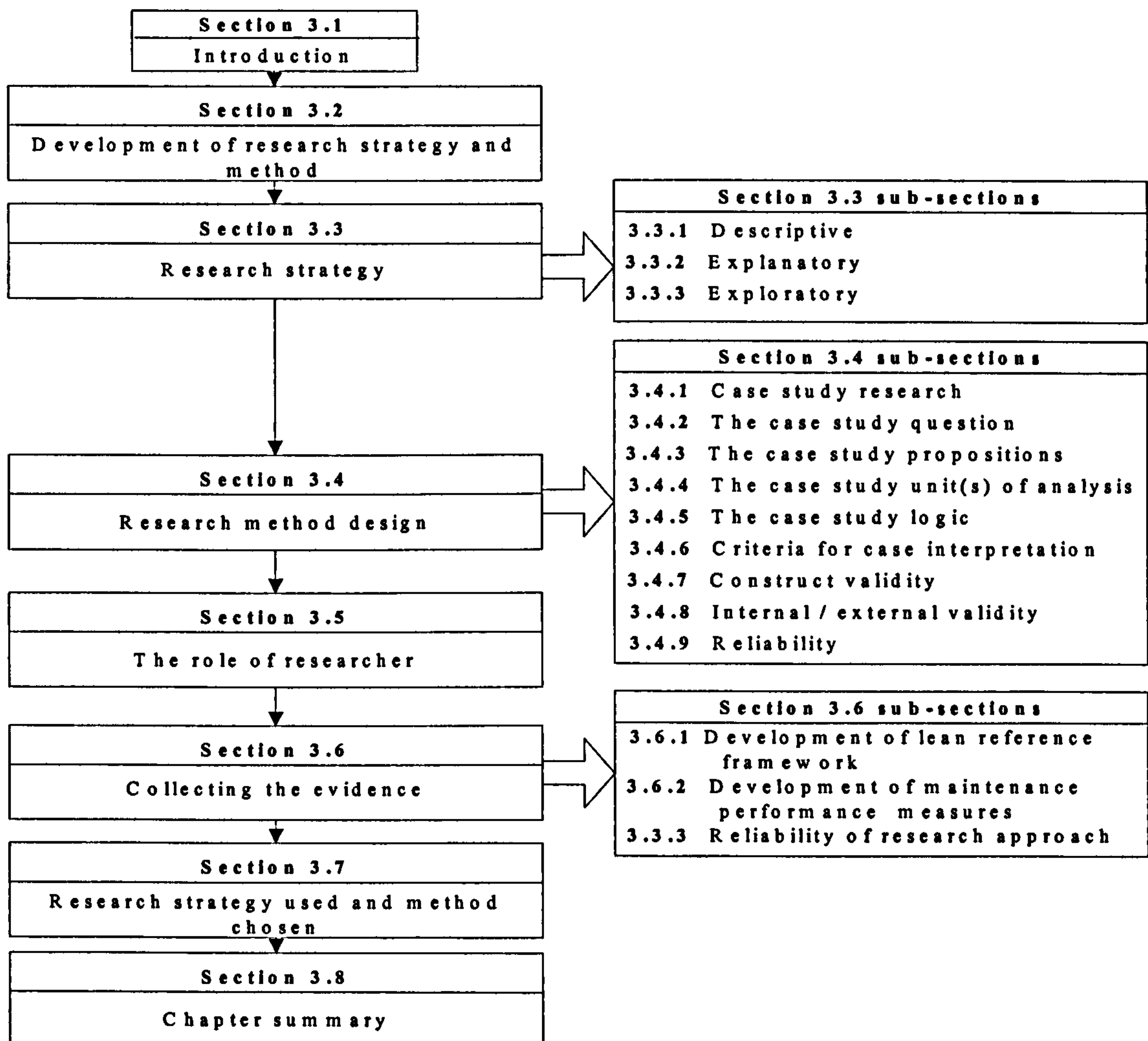


Figure 3.1 Layout of chapter three

3.2 Development of research strategy and method

The previous chapter discussed the combined issues of manufacturing systems, maintenance, lean production, lean thinking, lean enterprise, and measures of performance. Examination of the related practical and research issues showed that maintenance could benefit from a lean approach to align with the business objectives (e.g., sustainability, profitability) of an organisation. The aim of the research therefore, is to provide an answer to the research question: “how does lean thinking improve the effectiveness of the maintenance function?”

The literature described in the previous chapter enabled the research question to be developed. However, the literature also showed a lack of research in the required areas necessary to provide an answer to the research question. As such, in this type of research a hypothesis operates as a means to explore the subject further.

Research strategies are reviewed below and will be used as a basis to select an appropriate research method to test the hypothesis introduced in chapter two: “Lean thinking improves the effectiveness of the maintenance function”.

3.3 Research strategy

The aim of research is to provide valid or general explanations (Bordens and Abbot, 1988). As such, different strategies provide different ways or methods of obtaining valid or general explanations for research. Fundamentally, research strategies can be classified in three ways: surveys, experiments and case studies (Robson, 1993), to which they may be applied for the purpose of exploratory, descriptive or explanatory research methods (Yin, 1994). In brief, each strategy is appropriate for a particular research approach (Yin, 1994; Robson, 1993), for example:

- 1 Surveys are appropriate for descriptive research
- 2 Experiments are appropriate for explanatory research
- 3 Case studies are appropriate for exploratory research.

Additional strategies include historical and archival analysis that overlap the three strategy classifications (Yin, 1994). Situations may also arise where there is a choice between more than one strategy appropriate for a relevant situation. Yin (1994: p.9) states that:

“We can identify some situations in which all research strategies might be relevant (such as exploratory research), and other situations in which two strategies might be considered equally attractive... To this extent, the various strategies are not mutually exclusive. But we also identify some situations in which a specific strategy has a distinct advantage. For case study, this is when a ‘how’ or ‘why’ question is being asked about a contemporary set of events over which the investigator has little or no control”.

The first and most important condition for differentiating the available research strategies however, is to identify the type of research question being asked (Yin, 1994). According to Yin, the key is to understand that research questions have substance (what is my study about?), and form (am I asking a ‘who’, ‘what’, ‘where’, ‘why’ or ‘how’ question?).

An explanation of three strategy classifications, their purpose, and a relevant situation for these strategies is discussed here.

3.3.1 Descriptive

The aim of descriptive research is to portray an accurate profile of an activity or condition and ensure that the results are representative of the samples as a whole. Survey research is used to evaluate the behaviour and attitudes of subjects. They are used primarily for measuring existing attitudes on a variety of issues. Commonly used survey research methods are questionnaires, personal interviews, and telephone interviews. Both qualitative and quantitative data can be used. A relevant strategy situation for survey research is that it asks who, what, where, how many, and how much, focusing on contemporary events that do not require control over behaviour (Yin, 1994; Robson, 1993).

3.3.2 Explanatory

The aim of explanatory research is to explain and describe causal relationships, and uses qualitative and quantitative data to provide explanations. Associated with experimental research there are three basic designs: true experimental, quasi-experimental, and non-experimental. A relevant strategy situation for experimental research is that it asks how and why questions which focus on contemporary events, and often requires control over behaviour. For true experimental research, manipulation of one or more independent variables is conducted to investigate a resulting change in a dependent variable (e.g.,

laboratory tests). For quasi-experimental research, instead of the random assignment of cases to conditions found in true experiments, quasi-experiments begin with a group entity. The researcher then looks for an existing or ad hoc comparison group, for example before and after comparisons. Finally, non-experimental designs involve data gathering. The researcher investigates cases that are not randomly assigned to groups. No variables are manipulated; the researcher accepts the values that occur naturally among the cases, either presently or retrospectively. The researcher then examines the data to see what variables may be interrelated (Yin, 1994; Robson, 1993; Bordens and Abbott, 1988).

3.3.3 Exploratory

The aim of exploratory research is to find out what is happening and ask questions of new and emerging subjects, and is generally qualitative. Associated with case study research, it is used to answer questions that are applied in their real life context. Case studies collect data or evidence from many sources, and are used to assist a researcher to maintain a holistic perspective when approaching a complex 'real life' event - such as organisational and management processes. A relevant strategy situation for case research is that it asks how and why questions, focusing on contemporary events, and does not require control over behaviour (Yin, 1994; Robson, 1993).

3.4 *Research method design*

To analyse the effects of lean thinking and maintenance in manufacturing, case study investigation has been chosen as the most viable and real-world centred methodology to use. As a comprehensive research strategy, the case study's unique strength is in its ability to deal with a full variety of evidence – documents, artefacts, interviews, and observations while investigating contemporary issues within a real life context (Yin, 1994). For the purpose of this research, it is clear that the richest sources of data for investigations of the maintenance function in manufacturing are active, commercial operations rather than 'experimental systems', which may be practically constructed in other fields. This is supported by the previous review of literature, which principally comprises surveys and case studies as investigative methodologies. The use of case study research is to investigate how and why lean thinking may improve the effectiveness of the maintenance function. The issue now is, what case study method is the most appropriate to satisfy the research question?

3.4.1 Case study research

Overall, single case designs are justifiable under certain conditions, when it represents the critical case in testing a well-formulated theory, in the instance of a unique event, or where the case serves for a revelatory purpose (Yin, 1994). Multiple case designs are where independent innovations occur at different sites, but are part of a wider study. Nevertheless, although each site may be the subject of an individual case study, the study as a whole is a multiple case design. The use of a multiple-case design is considered to be more compelling and robust than single-case designs (Yin, 1994). For this reason, a multiple case study research has been chosen for this research. An example of a typical multiple case study approach is shown in Figure 3.2:

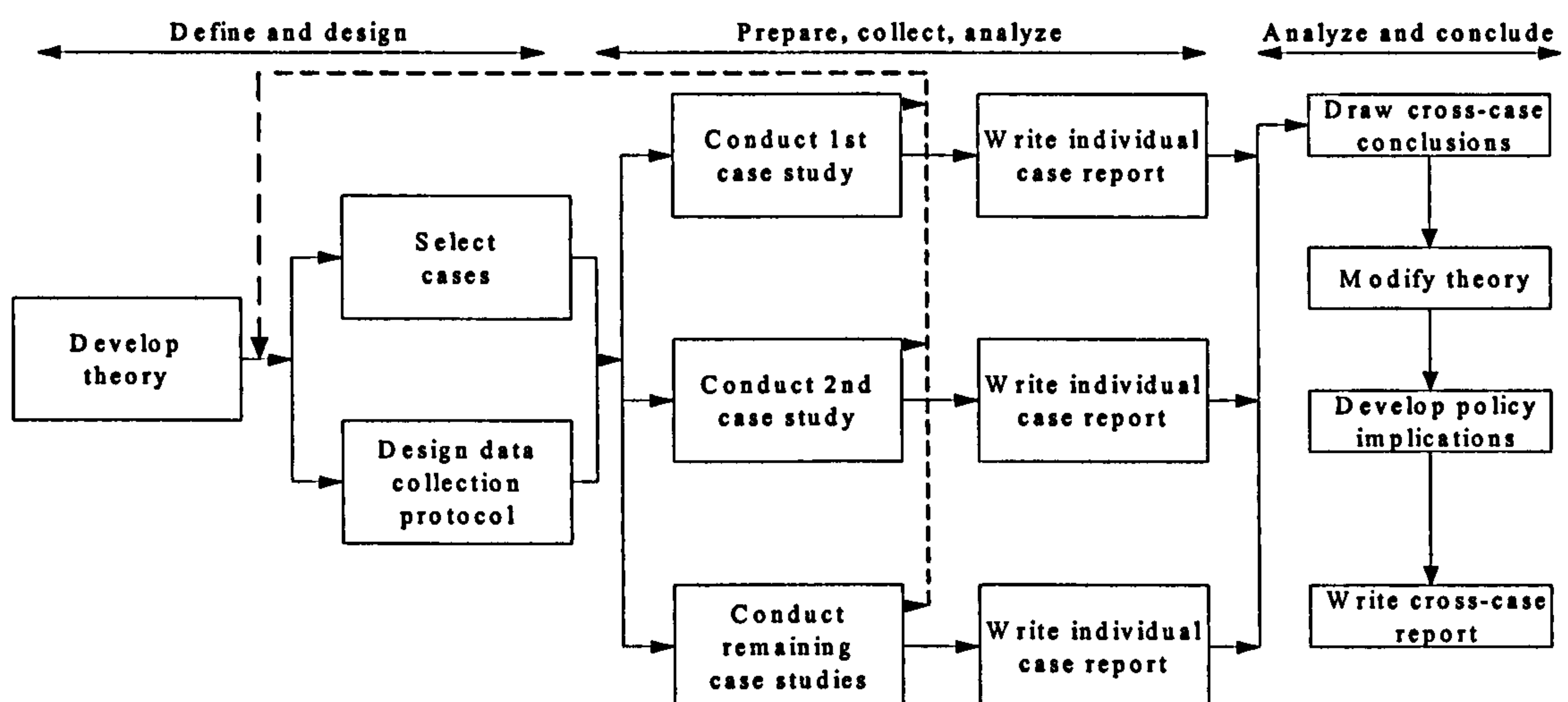


Figure 3.2 Multiple case study method (Yin, 1994)

There are five components of a case study research design, which are especially important (Yin, 1994):

- 1 The (case study) question(s)
- 2 The (case study) proposition(s), if any
- 3 The (case study) unit(s) of analysis
- 4 The (case study) logic linking data to the propositions
- 5 The criteria for interpreting the (case study) findings.

3.4.2 The case study question

The study question helps clarify the nature of the research, and for this investigation, sets out to understand how and why lean thinking may improve the maintenance function. For the purpose of the research, the question formulated from the literature review was: “how does lean thinking improve the effectiveness of the maintenance function?” As a basis for the case investigations however, a hypothesis is used: “Lean thinking improves the effectiveness of the maintenance function”

3.4.3 The case study propositions

The use of propositions direct the attention of the research toward the areas that should be examined within the scope of the study (Yin, 1994). For this research the use of propositions were considered to be more useful, practical and acceptable for real life case study investigations than developing a notional system to investigate an ‘unstructured problem’ as favoured by Checkland (1981). A core of Checkland’s approach is that all possible verbs should be used to describe the “root definition” (hypotheses) of an unstructured problem, then be investigated as a concept model. However, given the diversity of the organisations visited, their different manufacturing strategies and varied approaches to their maintenance policies, development of a notional lean maintenance system would be beyond the practical feasibility of this research. The propositions for this research are:

- P1 Establish the presence of lean thinking used by maintenance
- P2 Establish how lean thinking is used by maintenance departments
- P3 Establish how lean thinking affects the maintenance function
- P4 Establish if there is a practical use for lean thinking by maintenance.

3.4.4 Case study unit(s) of analysis

As a general guide, the definitions of the unit(s) of analysis (and of the case) relate to the way the initial research question(s) have been defined. For this research, the unit of analysis is the set of activities, actions, techniques, and approaches associated with the use of lean thinking by maintenance. This is in the context of the boundaries set by the

standard definitions of manufacturing and maintenance systems, and is investigated over a period of time.

3.4.5 Case study logic

The logic of a case study design should not only indicate what data is to be collected, but should also tell you what is to be done after the data has been collected. This is indicated by linking the data to propositions through “pattern matching”, as a way of relating pieces of information from a case to a proposition. It is also indicated that they may be interpreted in terms of comparing at least two rival propositions by the use of different patterns that are sufficiently contrasting.

3.4.6 Criteria for case interpretation

To determine a criteria for the quality of research designs, four tests are commonly used to establish the quality of empirical research, these are:

- 1 Construct validity
- 2 Internal validity
- 3 External validity
- 4 Reliability

3.4.7 Construct validity

Construct validity is used to establish correct operational measures for the concepts being studied (Yin, 1994). To increase construct validity, the use of multiple sources of evidence which converge is rated more highly in terms of their overall quality than reliance on single sources of information (Yin, 1994). For this research, archival records, documents, observations, interviews, and photographic evidence are used. Additionally, individuals within the companies researched reviewed case study outcomes and publications. For the purpose of this research the constructs are:

- 1 The use, or otherwise, of lean techniques and approaches used by maintenance to improve effectiveness are studied. To determine this, a comprehensive list of lean activities possible within a company, and maintenance in particular, is used as a

reference of identification. The development and use of a lean thinking reference framework is explored, presented, and discussed in more detail in chapter four. Direct observations, interviews, and documented information are also utilised to inform of change.

- 2 Measuring the performance of maintenance relating to lean techniques and approaches or otherwise are also studied. To determine this aspect of the research, the development of performance measures are undertaken to provide clues that will demonstrate change within maintenance. In chapter five, the development and use of a measure of maintenance performance is explored and discussed in more detail.

3.4.8 Internal / external validity

The focus of internal validity is used mostly for explanatory research and is used to establish causal relationships, “whereby certain conditions are shown to lead to other conditions, as distinguished from spurious relationships” (Yin, 1994). Whereas, external validity establishes the domain to which a study’s findings can be generalised. To establish external validity, a theory should be tested in multiple cases with replications within the findings of second and subsequent cases. Once this has been achieved, the results may be accepted for a much larger number of similar cases (Yin, 1994). For this research, a degree of external validity is established across a number of cases.

3.4.9 Reliability

The reliability of a case study should be able to demonstrate that the operations of a study - such as the data collection procedures, can be repeated with the same results (Yin, 1994). For example, could another researcher follow the same procedure and arrive at similar findings. For this research six different companies were visited to test the suitability and reliability of an information template for future case investigation. The outcome was that the investigation template did not require undue alteration for future use.

3.5 The role of researcher

For this research the role of the researcher is that of ‘participant-as-observer’. As participant-as-observer, the researcher surrenders to the everyday experience while in the natural setting, but instead of ‘going native’, remains committed to being a

researcher, and reports experiences as a member (Gill and Johnson, 1991). The approach of participant-as-observer to research does have its weaknesses however: it may be prone to selectivity unless broad coverage is given; it may be time consuming in terms of hours needed by the researcher(s); events may change as a result of observation. Nonetheless, the strength of this approach to research allows coverage of events in real time, it covers the context of an event and provides insight into interpersonal behaviour and motives (Yin, 1994).

Within the context of ‘observational research’ including the role of participant-as-observer, Gill and Johnson (1991) present a classification of the roles of an observer (Figure 3.3). As shown, the opposite to participant-as-observer is that of a spectator, who looks on events and processes but avoids becoming involved in any interaction with subjects:

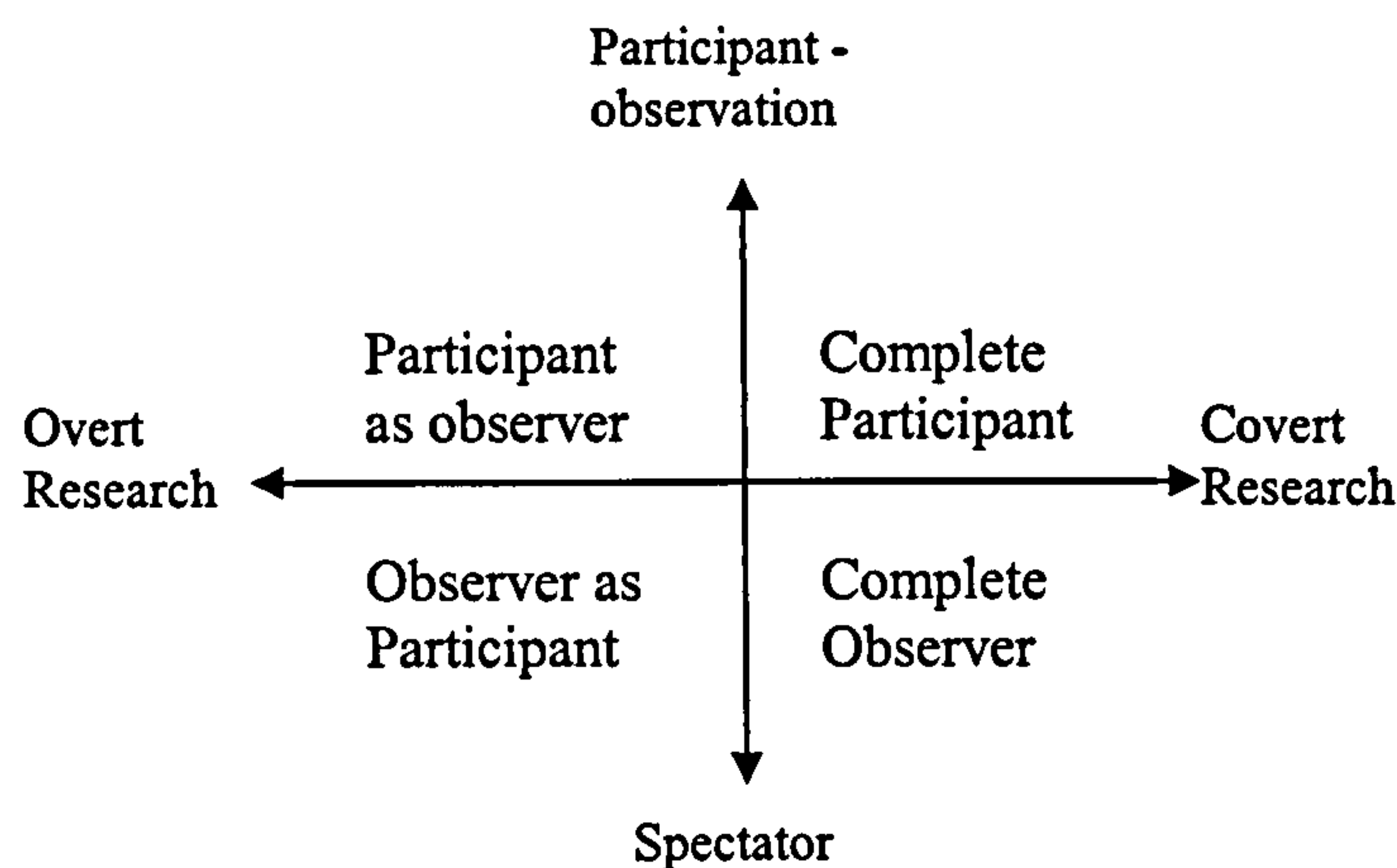


Figure 3.3 Classification of observer (Gill and Johnson, 1997)

In relation to participant-as-observer in Figure 3.3, overt research is where the subject(s) know(s) about, or is aware of the presence of the observer. Covert research is where the observer is hidden from the subject(s) and attempts to have the least effect on subject behaviour.

3.6 Collecting the evidence

Ideally, a perfect research situation would exist whereby there is dissimilarity between different companies concerning maintenance practices and lean techniques used. Those who use lean techniques within maintenance could be compared to those who do not. These comparisons could then be used to provide an answer to the research question. To contemplate this however, would be impractical, even for the basic reasons such as lack

of time, money, resources and compatibility. More appropriate, practical, and just as effective, is the selection and use of companies that use lean thinking within maintenance, in particular for case investigation. Figure 3.4 outlines the multiple case study approach to this research based on Yin's model presented in Figure 3.2:

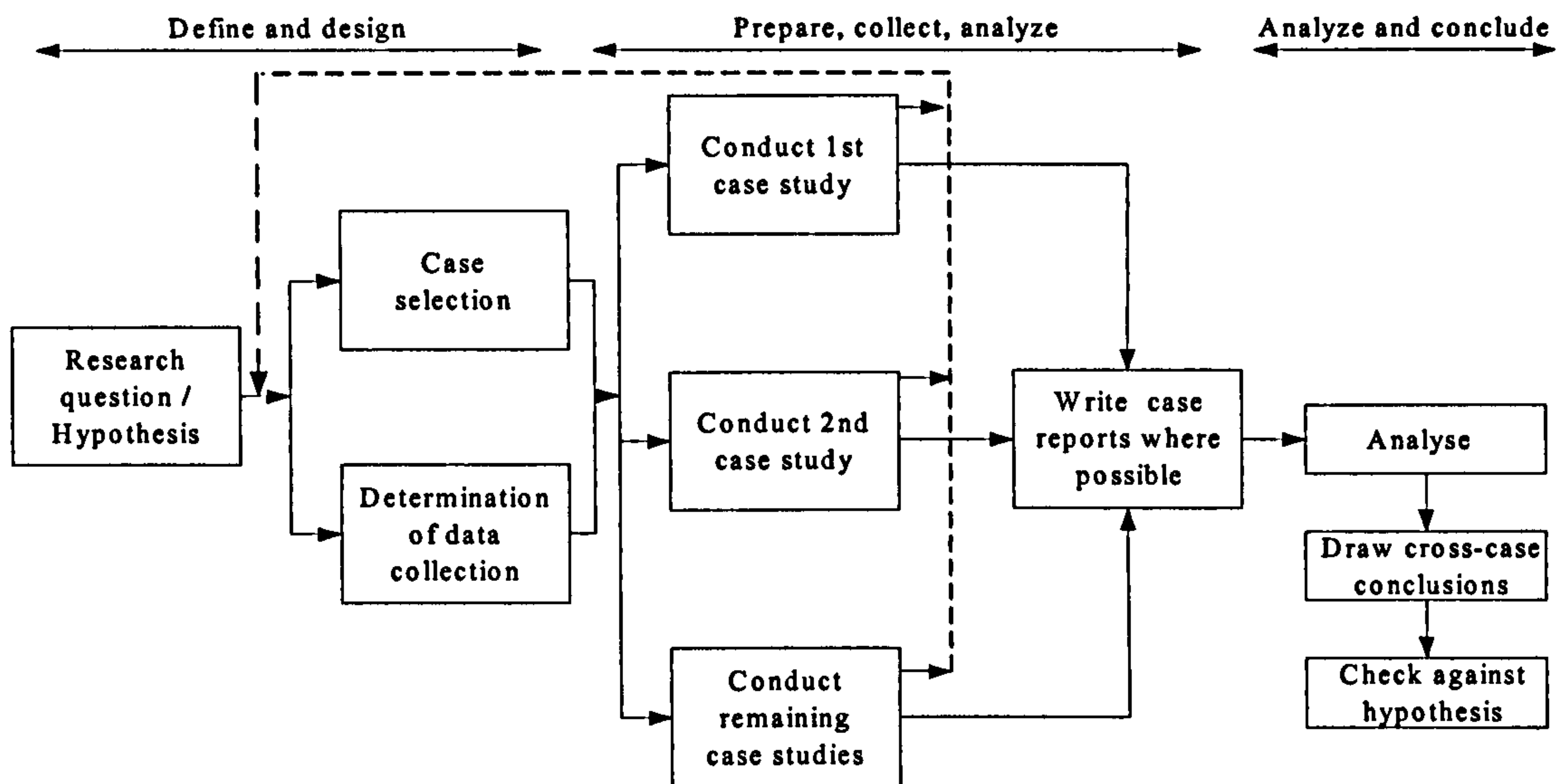


Figure 3.4 Multiple case study approach for this research

For this research, a mixture of U.K situated companies were approached by mail shot requesting help with ongoing research. Some were known (from previous research) to use characteristic elements of lean production, i.e., TQM, JIT and / or TPM. The remainder were approached with very little pre-knowledge of their background, using online business directories.

Determination of data collection focuses on qualitative and quantitative (where possible) information retrieval in the form of interviews, observations, documentation, recorded performance data, and photographs. A lean concept framework and maintenance performance indicators are used as a point of reference for case investigation. Whereas the lean framework provides scope and definition to the case questions, the performance indicators helped to understand and provide a focus for the raw data retrieved.

All case studies were conducted within a period of eighteen months. For each case study, the same approach was used. However, assumptions could not be made concerning the scale of lean, or use of performance measures prior to each visit. As such, flexibility was allowed for the different types of company, with different

approaches to their use of lean techniques and maintenance practice. To counter the possible loss of valuable information, especially during the early stages, notes were taken in the form of a diary record.

3.6.1 Development of a lean reference framework

For the case study research, two major points of reference required development: a lean thinking reference framework, and comprehensive framework of maintenance performance indicators. The performance indicators are discussed below.

✓ The development of a lean thinking reference framework is intended to represent the lean concepts possible within a company, and maintenance in particular, and serve at least three general purposes that:

- 1 Provide scope and definition for the case study investigation
- 2 Reduce errors of pre-judgement through flexible representation of the lean concepts possible within companies and maintenance
- 3 Provide a schema to develop appropriate and responsive forms of measurement that suit different conditions and situations. ✓

✓ Research has shown that a generally agreed point of reference or programme of lean concept use does not exist for maintenance. However, general approaches for implementing lean thinking concepts within organisations do exist. Three such approaches are presented here to provide a perspective for the development of a suitable lean reference framework used for this research: ✓

- 1 Take a systematic approach to implementation by introducing various techniques sequentially, e.g., Monden (1994) and Shingo (1989)
- 2 Implement techniques that match the internal and external needs of a company, e.g., Womack and Jones (1996a, 1996b)
- 3 Develop a strategy of implementation based on the connectivity between the links identifiable within a process and those that comprise lean thinking, e.g., Comm and Mathaisel (2000).

For this research, the first two approaches would be unworkable for a number of reasons. For example, TPM alone can take as long as three years to implement (Nakajima, 1988), and five to seven years if a range of concepts are to be implemented (Liker, 1998). The resources required accommodating such lengthy periods of implementation and investigation would also be too expensive. Sustainability over long periods of research cannot be guaranteed, as such may effect reliability. Repeatability would also be a problem, not just for the reasons presented (time, resources, and reliability) but also of trying to find 'like' companies for research. Furthermore, a best-fit approach could only be representative of one company site at a time.

Matching the requirement of this research more closely is the third approach presented by Comm and Mathaisel (2000). As guidance, the first three stages of their suggested eight-step strategy to integrate and use lean concepts provided a useful reference in developing a lean reference framework. The first three-stage-steps of Comm and Mathaisel's implementation strategy is to 'build the lean consortium', 'target potential stakeholders', and 'decide on the research agenda'. For the lean reference framework, this translated into seeking participants (company, industry, academic), seeking stakeholders (maintenance managers, technicians, operators) and representing the areas of interest.

Three of the five remaining implementation steps by Comm and Mathaisel (2000) also compared to other aspects of this research: 'testing the research approach', 'benchmarking' and, 'analysing and assessing the findings'. These relate to case study pattern matching and qualitative and quantitative case study research. The last two of the five steps: 'implementing lean concepts', and 'establishing controls for their implementation' do not concern this research.

3.6.2 Development of maintenance performance indicators

Findings in a case study are likely to be more convincing and accurate if based on different sources of information (Yin, 1994). As such, an overall measure of maintenance performance was developed using consequence variables, which through maintenance activity may possibly relate to the use of certain lean concepts. In particular, those concepts within the lean reference framework, in terms of their possible contribution to maintenance that could provide quantitative feedback.

As no single reference example could be found to compare with the needs of the research, examples were drawn from a variety of reference materials to develop an

overall measure of performance. The developed maintenance performance measures presented and discussed in chapter 5 were then assessed for their suitability during pre-case study investigations and company visits discussed within chapter six.

3.6.3 Reliability of the research approach

The reliability of the approach, tools and techniques used for the case study research were tested during six pre-case study company visits, (chapter six), and viewed against other contributions to similar research situations (e.g., Checkland, 1981; Karlsson and Ahlstrom, 1996; Sanchez and Perez, 2001; Soriano-Meier and Forrester, 2002).

Methods, models and techniques have been developed to assess the changes toward lean production (Karlsson and Ahlstrom, 1996), to explore the issues of lean indicators and manufacturing strategies (Sanchez and Perez, 2001), and to evaluate the leanness of manufacturing firms (Soriano-Meier and Forrester, 2002). However, the experience gained by the researcher during pre-case study company visits showed the developed lean reference framework as the most suitable and flexible approach to use. The required aim is to identify the presence and use of lean techniques within maintenance, not to operationalise the principles of lean production into variables of leanness (Karlsson and Ahlstrom, 1996). Neither is the framework intended (Soriano-Meier and Forrester, 2002) to survey managerial commitment to Karlsson and Ahlstrom's lean variables: 'elimination of waste'; 'continuous improvement'; 'zero defects'; 'JIT deliveries'; 'pull of materials'; 'multifunctional teams'; 'decentralisation'; 'integration of functions and vertical information systems' (although useful and possibly desirable, they may be misleading when investigating maintenance). Neither is the framework designed to develop an integrated checklist model to assess changes toward lean production (Sanchez and Perez, 2001).

Although the company visits highlighted the suitability of the developed maintenance performance measures to be used for investigation, appropriate literature comparisons could not be found.

Reflective of the observations made during pre-case study investigations, the practical use of storyboards, for example TPM and 5S, was included within the final approach. Nonetheless, the researcher is satisfied that a suitable method of investigation has been developed to answer the research question through the use of a hypothesis.

3.7 Research strategy used and method chosen

Figure 3.5 provides an overall summary of the research strategy and methodology used within this thesis:

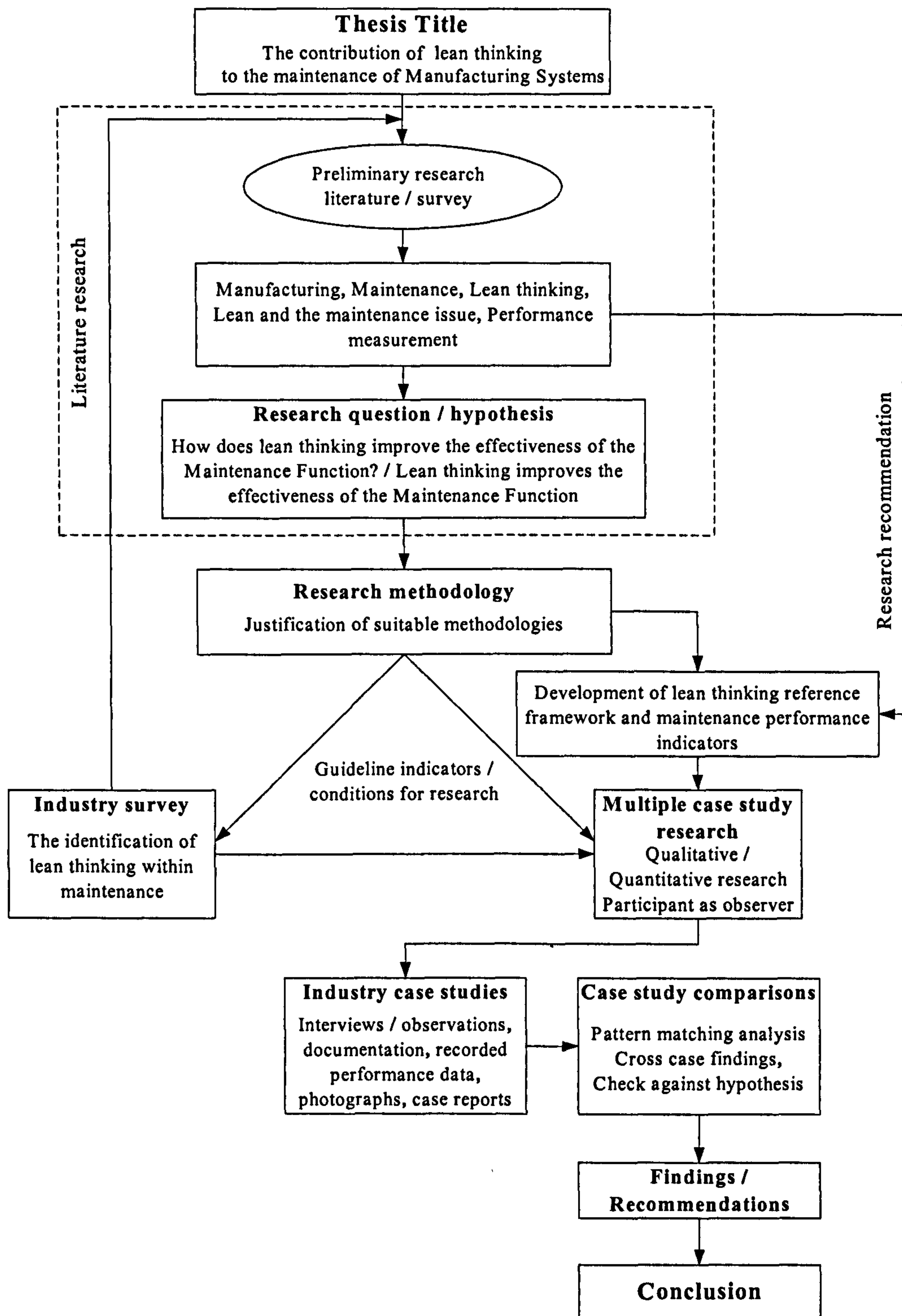


Figure 3.5 Overall summary of research strategy and methodology used within thesis

3.8 Chapter summary

The aim of this research is to provide an answer to the question developed in chapter two - “how does lean thinking improve the effectiveness of the maintenance function?” To answer this question through a hypothesis, a multiple case study investigation was chosen with the researcher’s role that of participant as observer.

A case study approach was considered appropriate to accommodate the exploratory nature of the research. Exploratory research is generally qualitative and is associated with a case study methodology. The aim is to find out what is happening and ask questions of new and emerging subjects. The study question clarifies the nature of the research, and for this investigation, sets out to understand how and why lean thinking may improve the maintenance function.

Chapter Four

Overview of lean thinking reference framework

4.1 Introduction

The aim of this research is to identify whether lean thinking improves the effectiveness of the maintenance function. However, earlier research showed that a point of reference or programme of lean concept use does not exist for maintenance. As such, a lean thinking reference framework for this research needs to be developed. Specifically, a framework that is representative of the lean concepts possible within a company and maintenance in particular, that provides forms of understanding, identification and measurement for investigation. Figure 4.1 provides a schematic representation of the structure of chapter four:

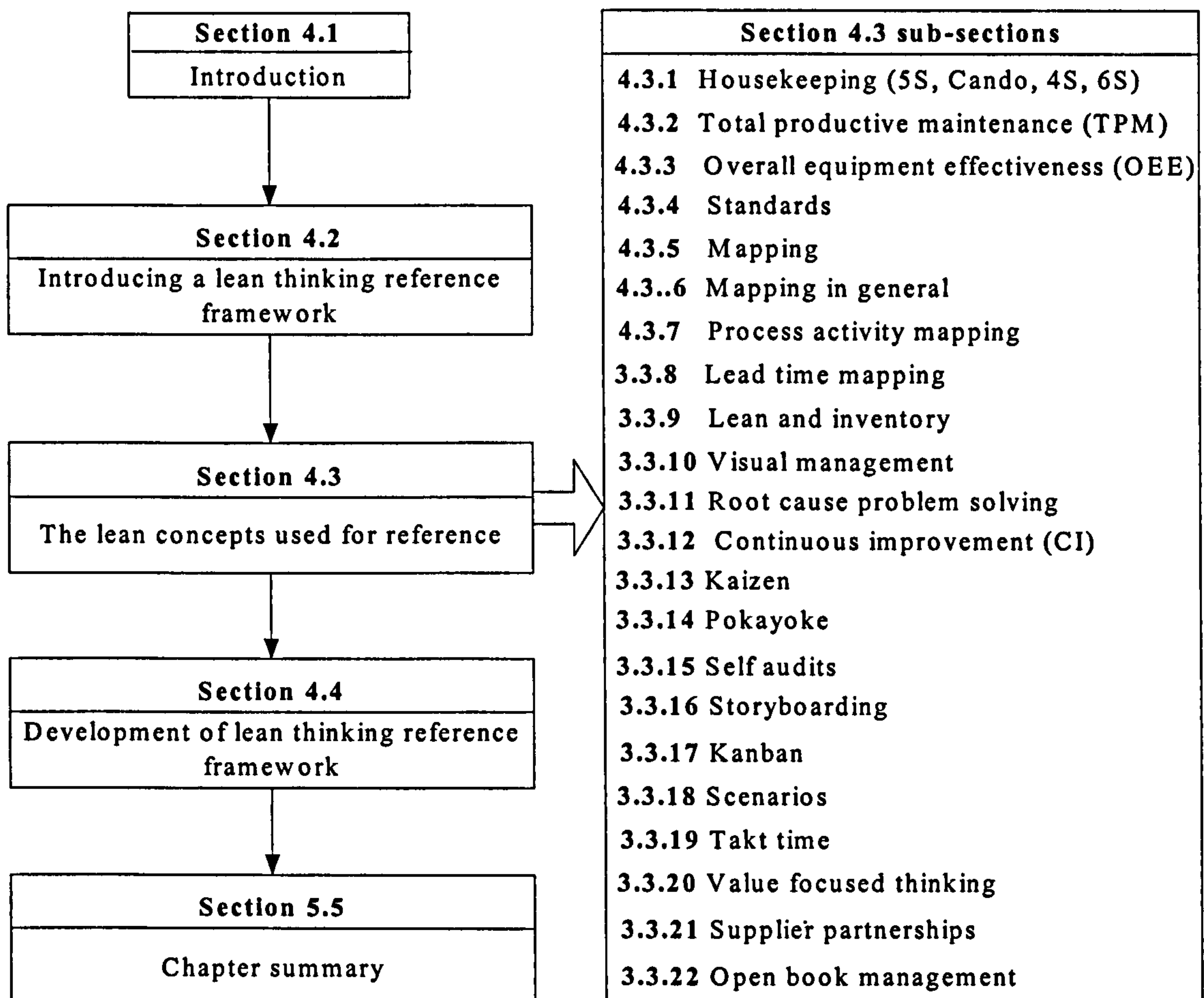


Figure 4.1 Layout of chapter four

4.2 Introducing a lean thinking reference framework

The review of literature in chapter two discussed the possible mutual relationship of lean thinking and the maintenance function, posing the question: “How does lean thinking improve the effectiveness of the maintenance function?” A subsequent hypothesis, “Lean thinking improves the effectiveness of the maintenance function” was proposed to explore and investigate the issues further. However, research also showed that as no reference for the use or implementation of lean concept use by maintenance could be referred to, a framework reference was needed. For guidance, a lean framework was based on the work presented by Comm and Mathaisel (2000), as it was considered the most suitable approach to the requirements of this research.

The purpose of the lean reference framework is to comprehensibly represent lean thinking concepts possible within a company, and maintenance in particular. Its use is to define lean concept presence within the companies visited, as they may be applied to the maintenance function. Additionally, those concepts within the framework whose possible contribution to maintenance may provide quantitative feedback are used to form the basis for development of measures for maintenance performance.

The structure of the lean framework is presented so that each concept issue is discussed separately if the need arises. As a result of new sources of information, additional concepts can be added without interruption. Separate discussion also allows the perceived benefits to be discussed more thoroughly to see if qualitative and / or quantitative research can be used to investigate their use by maintenance.

The lean framework does not advocate selectivity in terms of the sub-processes or techniques associated with lean concept use by maintenance, as to do so would create too much subjective bias from the researcher in determining levels of participant inclusion. For example, to stipulate that the presence and use of TPM by maintenance can only be included if the twelve steps of TPM implementation (Nakajima, 1988) have been rigorously followed would be unfeasible within this research. The twelve steps include: management declaration; education campaign; organisation development; establish policies; formulate master plan; TPM kick-off; focussed improvement; autonomous maintenance; early equipment management; training and skill development; quality maintenance; raise TPM levels.

4.3 The lean concepts used for reference

The research literature highlighted the theme, principles and characteristics of lean thinking. In relation to the central theme of lean, which is the elimination of waste, Figure 4.2 provides a representation of wastes possible within maintenance analogous to the lean production / organisation wastes proposed by Ohno (1988) and Bicheno (2000). In this context, the concepts that comprise the lean reference framework are presented and discussed here:

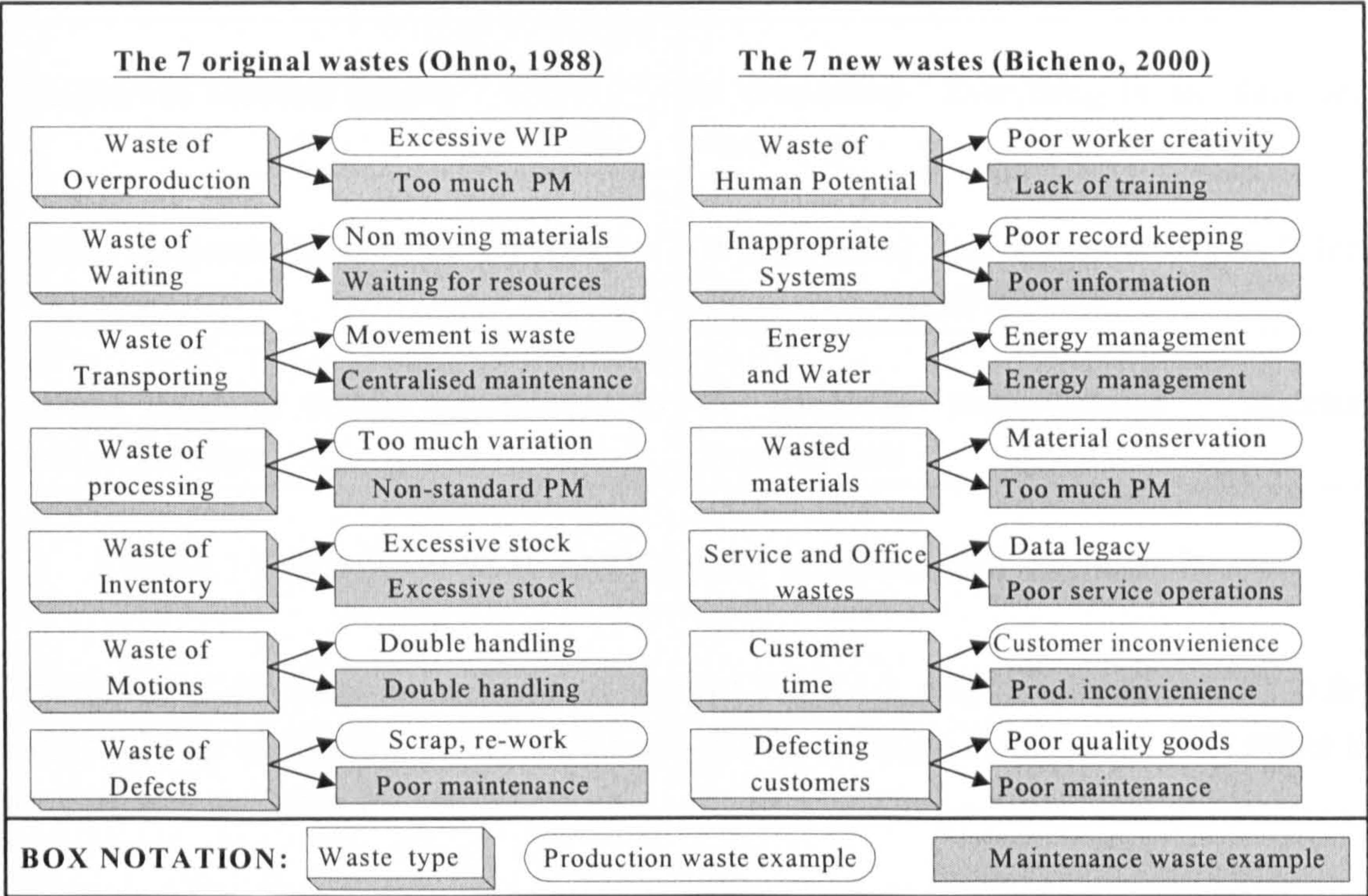


Figure 4.2 Lean wastes and analogous wastes within maintenance (Davies and Greenough, 2001)

4.3.1 Housekeeping (5S, CANDO, 4S, 6S)

Housekeeping is considered the cornerstone of lean thinking, is fundamental in lean environments, and is considered the first stage to be implemented within companies (Bicheno, 2000). Housekeeping is commonly referred to as 5S within Japanese organisations, or CANDO (Bicheno, 2000) in Western companies. Table 4.1 provides a description of 5S (CANDO) principles:

5 S	CANDO
Seiri (Sort) Separate all unnecessary items and eliminate them from the workplace	C (Cleanup) Remove all items not required within a period ahead. Review workplace layout
Seiton (Straighten) “A place for everything and everything in its place”	A (arrange) Make the workplace easy to work in. Recognisable work locations
Seiso (Scrub) Maintain tidiness	N (Neatness) Everything in its place and ready to go
Seiketsu (Systemise) Make cleaning as part of the work day	D (Discipline) Aim to keep factory in “Chief executive’s visit all the time”
Shitsuke (Sustain) Sustain commitment to previous four steps	O (Ongoing improvement) Maintain improvements

Table 4.1 Principles of 5S (CANDO) (after Monden, 1994; Bicheno, 2000)

Description of 4S refers to the first four steps of Table 4.1, and 6S normally refers to the additional step of ‘Adding safety’ (Bicheno, 2000), although Nakajima (1988) refers to the sixth step as “Let’s try hard”.

As a foundation for improvement and a methodology to diminish slack hidden within operations (Monden, 1994), the emphasis of 5S (CANDO) is upon participation. The perceived benefits of those steps considered useful in operations is that of improving quality, lead times, and cost reduction. In maintenance, these attributes can be related to improve asset maintenance, contributing to improved quality, reduced downtime and cost of repair.

Essentially, 5S (CANDO) is an ongoing process integrated with the activities of the organisation, making its direct contribution difficult to separate from other activities. As such, its contribution to the effectiveness of maintenance may be evaluated qualitatively through participant interviews, observations, and a process of pattern matching through multiple case study analysis. Furthermore, although it is possible that other definitions exist for similar terminology, for this research this activity will be referred to as 5S from now on.

4.3.2 Total productive maintenance (TPM)

TPM is a company-wide approach to maintenance, aimed at downtime that emphasises prevention rather than reaction (Nakajima, 1988).

One of the perceived benefits of using TPM is improved asset uptime. Its contribution to the effectiveness of the maintenance function can be evaluated in a qualitative manner. Likewise, where raw data is available, quantitative methods may also be used that could provide additional clues in certain situations. For example, the effectiveness of TPM upon maintenance may be reflected in a reduction of recorded repair hours and breakdown frequency. Preventative and predictive maintenance activity measurements may also possibly indicate whether too much or too little prevention maintenance is carried out.

4.3.3 Overall equipment effectiveness (OEE)

OEE is a measure of equipment performance efficiency and is linked directly to 5S and TPM.

As a monitor for production, the emphasis of OEE is to maintain operational improvement with the perceived benefit that it will help increase asset availability. Evaluation from a qualitative perspective is possible. Quantitatively however, OEE as a measure would be unsuitable as it focuses mostly on production losses in which maintenance policy is only one effect among many. Although considered useful, trying to calculate OEE beyond the scope of a particular machine or line to include the plant with a degree of accuracy would be questionable (Bicheno, 2000). Nonetheless, by applying the principles of OEE, reduced values of downtime caused by breakdowns may help indicate the effectiveness of maintenance upon machine performance rates.

4.3.4 Standards

Standards within the lean context refer to the standardisation of the workplace and worker participation. With the exception of ISO standards 9000, and 14001 for example, it focuses on production through promotion of greater worker ownership in the manufacturing process (Bicheno, 2000). Ohno (1988) cites Ford (1926), as instrumental in developing and realising standardisation within the Toyota production system. Essentially, the aim of standardised work is to achieve the best way to get the job done

in the amount of time available, and how to get the job done right, the first time every time (Womack and Jones, 1996b).

As a lean concept, emphasis is on improvement with the perceived benefit of standardising work throughout. Although focus centres on production, the use of standards may also possibly be present within the maintenance function. Qualitatively, participant interviews, observations, and the process of pattern matching through multiple case study analysis may be used to understand the use of standards within maintenance. Quantitatively, raw data may also be available to highlight the effects of standardising practices particularly within maintenance. For example, standardised work may result in the reduction of maintenance hours worked within a company.

4.3.5 Mapping

In a broad sense, mapping and mapping techniques within a lean context are methodologies used to differentiate value from waste within companies, organisations, and enterprises. An abundance of material and information on mapping techniques exists, and are represented by important texts such as the 'Seven value stream mapping tools' by Hines and Rich (1997), and 'Learning to see' by Rother and Shook (1998). Although these contributions contain valuable insights and can not be ignored, there is no reference to the maintenance function within them. Additionally, Bicheno (2000) who relates to both pieces of work and that of others, and covers many types of mapping, does not mention maintenance either. However, it may be possible that some maintenance departments do use mapping techniques to help identify and eliminate waste.

Practically, it would be unfeasible to include all the available types of mapping techniques within the reference framework. To overcome the problem of what type to use, the work of Hines and Rich, Rother and Shook, and Bicheno are used to select three types of mapping technique for the framework. These are types of mapping that not only contribute to waste elimination within the context of manufacturing, but may also contribute to the possible elimination of waste within maintenance.

As way of explanation for the sources used, Rother and Shook use mapping to illustrate the 'big picture', which include the product, the company, and the supply chain, to identify and eliminate waste. Hines and Rich outline a decision making process to map the value stream or supply chain based on Ohno's (1988) seven Toyota wastes, in addition to those identified for a particular company under investigation. Bicheno

(2000) in 'The lean toolbox' provides useful pointers for the various types of mapping available. The choice of mapping types is discussed here:

4.3.6 Mapping in general

In terms of the big picture, simple mapping techniques such as string diagrams may possibly be used by maintenance to trace, then simplify and establish the efficiency of activity and resource movements. The lean emphasis of this approach focuses on a given process, with task improvement as a perceived benefit. Qualitatively, participant interviews, observations, and the process of pattern matching through multiple case study analysis may be used to understand the contribution of mapping. Quantitatively, raw data may also be available that could highlight the effects of mapping. For example, mapping may show a more efficient way of reducing transportation, which may in turn result in a reduction in overdue tasks by maintenance.

4.3.7 Process activity mapping

✓ Process activity mapping is a method of identifying, documenting, evaluating and overcoming non-value-adding activities throughout an organisation. As one of the seven mapping tools proposed by Hines and Rich (1997) the emphasis of this approach is to seek improvement through criticism. The first stage of this method is to develop an overall picture of a process, then record and detail all the actions, time taken and people involved within that process. From the recordings, wastes are then acted upon to seek a best approach solution. The additional six tools proposed by Hines and Rich (1997) are: ✓

- 1 Supply chain response matrix - time compression and logistics movement
- 2 Production variety funnel - seeks to identify variety along a supply chain
- 3 Quality filter mapping - mapping to identify where quality problems exist in the supply chain
- 4 Demand amplification mapping - focuses on how demand changes along a supply chain in terms of excess inventory, production and labour and capacity
- 5 Decision point analysis - perceived useful to assess the point within a supply chain that operates both upstream and downstream processes

6 Physical structure mapping - visualising the value stream at industry level

It is recommended that process activity mapping should be an ongoing activity for improvement. However, although its contribution to the effectiveness of the maintenance function can be assessed qualitatively, quantitative information may be harder to attain. Nonetheless, in terms of its lean emphasis (time) and the perceived benefit of improving utilisation, clues may be attainable that show improved utilisation of manpower, time, resources and possible reduction in scheduled service costs.

4.3.8 Lead-time mapping

✓The aim of lead-time mapping is to track, quantify, and prioritise the various elements of total production lead-time. The lean emphasis of this type of mapping is time, with a perceived benefit of being able to evaluate lead-time breakdown. The focus of lead-time mapping looks at:✓

- 1 Order entry issues - time from receipt of order to start of manufacture, configuration time, time of system entry to completion
- 2 Procurement - time to procure materials and bring to point of use
- 3 Non-specific manufacturing time - focus on assembly variety
- 4 Order-specific manufacturing time - focus on manufacturing stages for order or customer-specific situations
- 5 Post production and store time - time between manufacture finish and delivery
- 6 Delivery time - bundling of orders.

Focusing on this type of mapping exercise to control production may of course have an indirect impact upon the activities and effectiveness of the maintenance function. To what extent the impact may be, can be qualitatively assessed through subjective feedback from practitioners. However, a quantitative link between the effects of lead-time mapping and maintenance effectiveness may be too tenuous to show clearly.

4.3.9 Lean and inventory

From a lean perspective, inventory and its control within manufacturing concerns the elimination of waste. As an important feature of the Toyota production system's JIT philosophy, Ohno (1988) views excess inventory as hiding many problems and is seen as the greatest waste of all. From this point of view, purposeful reduction of inventory is seen as a way of uncovering and addressing problems to eliminate waste within a production system (Suzaki, 1993). As an essential feature of Ohno's JIT goal, inventory reduction is stated in terms of absolute ideals (Hopp and Spearman, 2000). Hopp and Spearman relate to the concept of zero inventory as an absolute ideal, and although recognising that zero inventory is an impossibility, it is a concept that stimulates constant improvement. They summarise the goals of JIT in terms of the 'seven zeros':

- 1 Zero defects avoid disruption of workstations requiring materials just in time - it is essential that the parts be of good quality. Since there is no excess inventory to make up for the defective part, defects will cause delay.
- 2 Zero (excess) lot size - In a JIT system, the goal is to replenish stock as it is taken by a downstream workstation. Maximum responsiveness is maintained if each downstream station is capable of receiving parts one at a time. If replenishment is in large batches of different parts, then inventory becomes less manageable with possible delays. The goal of single supply is commonly referred to as a lot size of one.
- 3 Zero set-ups - Essentially, the elimination of setup is a precondition for achieving lot sizes of one. The aim here is to run longer between set-ups, as too frequent set-ups can degrade capacity.
- 4 Zero breakdowns - Without excess work in progress (WIP) in a system to buffer machines against downtime, breakdowns may bring production to a halt. Therefore, an ideal JIT system cannot tolerate unplanned downtime.
- 5 Zero handling - If parts are made exactly in the quantities and at the times required, then handling must be kept to a minimum. The ideal is to feed material directly from workstation to workstation. Additional movement will require parts to be made earlier than needed, thus adding time to the process.
- 6 Zero lead-time - The goal of zero lead-time is equivalent to perfect just in time flow and is close to the core of zero inventory.

- 7 Zero surging - Surges occur within a JIT system when sudden changes in product demand occur within a production plan requiring response. Unless excess capacity is available within the system, disruptions or even stoppage will occur.

In practice, the seven zeros are no more achievable than zero inventory. For example, zero lead-time with no inventory would be impossible. Nonetheless, they are goals to achieve continued improvement. As such, the practice of purposefully reducing inventory can be seen as a way of uncovering and addressing possible wastes associated with the seven zeros presented here.

Recent literature (Fortuin and Martin, 1999; Botter and Fortuin, 2000) concerning maintenance spare part requirements (streamlining inventory) has alluded to the basic approach of inventory reduction (the lean approach). Nonetheless, how well a lean methodology of inventory control transfers to the maintenance function is still not clear. For this research, if a lean approach to inventory (including reduction techniques) is practised by maintenance, then qualitative research may reveal this through interviews and observations. Additionally, quantitative data may also indicate (where possible) the effects. For example, manageability of spare parts within a lean environment may possibly result in improved inventory turnover rates.

4.3.10 Visual management

As a lean characteristic, visual management is management by sight, to 'see' the factory - its work flow, its performance in terms of flow, and opportunities for improvement (Henderson and Larco, 1998). It is also about implementing automation through the use of visual controls such as 'Andon' board lights, standard operations sheets, digital display panels, and storage and stock plates. Andon is the name given by Toyota for an indicator board that shows when a worker has stopped a line; usually red for machine trouble, white for the end of a production run, green for material shortage, blue for a defective unit, and yellow for a required set-up (Monden, 1994). The practice of visual management is closely associated with the practices of 5S (CANDO) and TPM within companies.

As with 5S and other lean techniques, visual management is an ongoing process integrated with the activities of the organisation. This makes its direct contribution difficult to separate from other activities. As such, its contribution to the effectiveness of maintenance may be evaluated qualitatively through participant interviews, observations, and process of case study pattern matching.

4.3.11 Root cause problem solving

Root cause problem solving is a process used to trace the cause of a defect, failure or interruption in a product or service. Root cause problem solving is considered fundamental to the philosophy of lean, and in particular the Toyota production system (Bicheno, 2000). Toyota utilise the term '5 Whys' for their method of tracing the cause or failure of a product or service, by simply asking 'why' five times when confronted with a problem. The 5 whys method is used to uncover and resolve less obvious problem causes for continued improvement (Ohno, 1988). Overall, the lean emphasis of root cause problem solving is product and process improvement, with the perceived benefit of assisting defect elimination. /

Qualitatively, the use of root cause problem solving within the maintenance function may be evaluated by participant interviews, observations, and case study pattern matching. Quantitative evidence may also be available that could provide clues to the use of root cause problem solving within maintenance. For example, a reduction of unscheduled maintenance tasks may be a result of implementing root cause problem solving techniques. However, consideration has to be given to the fact that a reduction in unscheduled task times may also be the result of other activities, not just root cause problem solving.

4.3.12 Continuous improvement (CI)

Continuous improvement (CI) or rather continual improvement, is a key lean thinking philosophy and is an extension to complimentary improvement approaches within and outside of TPM, OEE and 5S (Bicheno, 2000). Fundamental to Kaizen (discussed in the next section) CI is considered by some practitioners as indispensable-yet-no-different from Kaizen. However, CI exclusive of Kaizen (small but frequent gains) and Kaikaku (e.g., Kaizen blitz, aggressively focussed production improvement exercises) is the philosophy of self-improvement and contribution. It is a mindset inextricably linked to maintaining and improving standards (Imai, 1986), and has as much to do with personal development and contribution as formulated practice. The lean focus and emphasis of continuous improvement is Gemba (Bicheno, 2000), i.e., the workplace, where waste elimination and change should and does take place. An example of the perceived benefit of continuous improvement would be improved shopfloor efficiency.

Qualitatively, the mindset of continuous improvement within the maintenance function may be evaluated by participant interviews, observations, and case study pattern matching. As an integral element of many of the lean techniques and approaches,

quantitative evidence of the use of continuous improvement within maintenance may be difficult to establish. However, it may also be possible that indirect clues may provide an insight to the contribution of continuous improvement, especially in areas such as improved levels of maintenance manpower efficiency.

4.3.13 Kaizen

Kaizen is a philosophy and set of tools dedicated to small increments of continuous improvement at all levels of a company. The philosophy of Kaizen states “Quality begins with the customer”, as customer expectations change and standards rise, so must the expectation and standards of the provider (Bicheno, 2000). Kaizen strategy (meaning ‘improvement’ in the Japanese definition) is considered the key to Japanese competitive success and differs from the Western interpretation. Whereas the Japanese are process oriented, Western companies focus upon innovation and results (Imai, 1986). At a basic level, Kaizen also differs from the concept of continuous improvement in that it has a defined structure. Managers are responsible for implementing and monitoring Kaizen, supervisors are responsible for applying it, and shopfloor employees make suggestions for improvement, learn new jobs, and are drivers for change (Bicheno, 2000).

The tools of Kaizen are varied and generally consist of other lean techniques such as 5S, the 5 Why’s, visual management, and the ‘PDCA cycle’ - plan, do, check, action. The PDCA cycle is an adaptation of the ‘Deming wheel’, which stresses the need for constant interaction among research, design, production, and sales to arrive at an improved quality that satisfies customers (Imai, 1986). Although available literature is heavily biased toward manufacturing and production, and improvements rather than maintenance, the essential message is that Kaizen standards exist only to be superseded by better standards. In this context and mindset it is not unreasonable, with its lean emphasis of improvement and perceived benefit of waste elimination to expect that Kaizen practice within a company would include the maintenance function.

If Kaizen is used within the maintenance function, participant interviews, observations, and case study pattern matching could be used as an investigative tool. As with other lean techniques, Kaizen is an ongoing process integrated with other activities, which makes its direct contribution difficult to separate and measure quantitatively. However, it may be possible to gain a quantitative insight to the overall contribution of Kaizen, especially in areas such as improved maintenance costs per unit of production.

4.3.14 Pokayoke

✓ Pokayoke (mistake proofing) classified and developed by Shingo is the use of jig(s), fixture(s) or sensor devices that ‘help achieve a one hundred percent acceptable product by preventing the occurrence of defects’ (Bicheno, 2000; Shingo, 1989). There are two kinds of Pokayoke: one is a mechanism to prevent human error, the second is a mechanism that catches a persons’ attention as soon as human error is made (Suzaki, 1993). From a Western perspective, this approach and the techniques used for defect prevention and human error may sometimes be referred to as mechatronic problem solving.

Shingo (1989) differentiates between maintenance and production with regard to Pokayoke, in that Pokayoke is essentially manufacturing focussed, whereas maintenance and in particular the elimination of machine breakdowns, is really a part of operational improvement. It is however still a form of process improvement in the Toyota production system, and as such should be seen as a contributor, for example in the use of Andon boards, and visual management.

Qualitatively, the tacit association between Pokayoke and maintenance activities may be understood more fully through interviews, observations, and case study pattern matching. From a quantitative point of view, information and the contribution (or lack of), of Pokayoke techniques possibly used by maintenance would be difficult to separate and measure. However, it may be that the effects of Pokayoke could reflect in areas of improved production output and reduction in the number of repairs over a given period. As stated by Shingo (1989), “taking thorough corrective repairs in response to trouble are essential, but when troubles do arise, it is the actual solutions to these problems that are the most important”.

4.3.15 Self-audits

Self-audits, or otherwise called self-evaluation questionnaires are considered useful for identifying areas of opportunity or weakness by lean thinkers, who consider standards and discipline fundamental to continuing improvement (Bicheno, 2000). They are used to develop creativity, clarity in vision, customer orientation and problem solving capabilities (Suzaki, 1993). There are several approaches to self-audits: award simulation, peer involvement and, workshop audits. Award simulation involves writing a submission as if applying for an award. Peer involvement makes use of in-house teams to write their own assessment using a (loose) framework as a guideline. Workshop audits use training exercises aimed at standardising an approach and is

agreed though consensus (Bicheno, 2000). Other approaches may be less formal and simply involve questionnaires, but would depend upon the type of organisation.

Overall, the lean emphasis of self-audits is improvement and visibility, with the perceived benefit of continuing self-evaluation, which leads toward greater ownership, responsibility, and contribution. However, as with other lean techniques, the direct contribution of self-audits to any particular activity within an organisation would be too difficult to separate and measure quantitatively. As such, its contribution (if used) to the effectiveness of maintenance may be evaluated qualitatively through participant interviews, observations, and process of case study pattern matching.

4.3.16 Storyboarding

A storyboard is simply a graphic series of panels on which information is displayed for personnel to refer to. Updated regularly, these boards (although their contents are determined by individual organisations) generally consist of financial figures and savings, control charts, progress charts, quality, safety and environmental issues, training procedures, and fault analysis examples such as the 5 Whys, cause and effect (fishbone) diagrams and 'Pareto analysis'. The use of cause and effect diagrams assist in PDCA cycle procedures for problem solving. From a maintenance perspective, Pareto analysis is used to help companies prioritise actions to improve performance and highlight areas in need of continued improvement. For storyboard presentation, Pareto analysis may be in the form of the top ten by asset, by fault etc., and best performers.

The lean emphasis of storyboarding is visibility, with the perceived benefit of improving information access. Storyboards have no direct impact upon the effectiveness of the maintenance function; they are merely information reference points. However, qualitative investigation through interviews and observations may provide an insight into their usefulness (or lack of) to the maintenance function.

4.3.17 Kanban

The Kanban ('tag') system is a method of information control designed to maximise the potential of the Toyota production system. As presented in chapter two – literature review, section 2.5.3, Kanban is the tool for managing and achieving JIT-production philosophy (Ohno, 1988; Shingo, 1989; Monden, 1994). As a tool to achieve JIT production (and leanness) Kanban is seen as pivotal in the aim to eliminate waste in all areas and in particular, overproduction (Ohno, 1988). The two types of Kanban

commonly used are withdrawal and production ordering (other Kanban types would include, vendor and supplier Kanbans). A withdrawal Kanban specifies the product quantity a process should withdraw from a preceding process. A production-ordering Kanban specifies the making and quantity of product the preceding process must produce. /

To achieve and realise the JIT purpose of Kanban, five certain rules must be followed (Ohno, 1988; Monden 1994). These five rules are:

- 1 The subsequent process should withdraw the necessary products from the preceding process, in the necessary quantities, at the necessary point in time
- 2 The preceding process should produce its products in the quantities withdrawn, by the subsequent process
- 3 Defective products should never be conveyed to the subsequent process
- 4 The number of Kanbans should be minimised
- 5 Kanban should be used to adapt to small fluctuations in demand (fine tuning of production Kanban).

Rules one and two above do have sub-rules pertinent only to the production aspect of JIT. For example, a sub-rule of rule one is “A Kanban should always be attached to the physical product” (Monden, 1994). Sub-rules are in general, purposefully included to emphasise the rule.

Kanban has been around for many years and is well established in a large number of companies. It is the classic signalling device for production pull systems (Bicheno, 2000). However, despite its long established use by companies such as Toyota, and its rigorous methodology for achieving the JIT philosophy, the researcher could not find examples of its use for maintenance. Although literature does exist concerning the suitability of maintenance policy with respect to factors defining a given production system, in JIT for instance there is no evidence to suggest that Kanban is used to pull maintenance activities for repair. For example, Azadiver and Shu (1999) conducted experimental simulation research for the order of preference of maintenance activities within a JIT environment. The motivation for their work was based on the lack of previous research within this area. Their research, although taking into account the characteristics of JIT, did not include the use of Kanban however. Interestingly, their

outcome recommended that predictive maintenance was more preferable than reactive maintenance within a JIT environment, but only within a certain range of their values. Beyond these values, differences between the maintenance policies used such as predictive, reactive or scheduled showed no significant difference.

The lean emphasis of Kanban is to seek synchronisation through pull, of which a perceived benefit would be task control. For investigation, qualitative research through interviews and observations may be used to identify the use of Kanban by production for maintenance. Additionally, it may be possible, that if maintenance Kanbans are used, quantitative information could provide clues to its contribution, or lack of it. For example, if predictive or preventative maintenance activities are pulled by production, then better management (or lack of) of task control may be more noticeable. Similarly, changes of work order schedules, planned or otherwise, if recorded may also be more noticeable.

4.3.18 Scenarios

Scenarios as described by Bicheno (2000), focus on simulating events, procedures, activities, and ideas for lean improvements. Bicheno recounts how the company Shell compares major projects against two or three scenarios, of which they are expected to demonstrate robustness and workability. As a way of learning about an organisation and its environment, Bicheno also describes how the use of scenarios instead of forecasts is consistent with the pull decision-making process of lean, as in starting from the future and working back. Although sensitivity analysis could be used to indicate the likely accuracy of such measures, emphasis here, is more about organisational learning and generating ideas rather than trying to measure the impact of scenarios.

With a perceived benefit of improving organisational learning, the lean emphasis of scenarios is (decision) pull. From a maintenance or production perspective it would be very difficult to measure quantitatively the impact of scenarios. However, its contribution may be qualitatively assessed through interviews and observations, in particular for the maintenance function.

4.3.19 Takt time

Takt time is fundamental to the uniform rate of progression of products through all stages of a manufacturing system, from raw material to the customer (Bicheno, 2000). The use of Takt determines the time to produce an item at the rate the market needs it

(Henderson and Larco, 1999), and is calculated by the number of work hours, whether per-day, week or month, divided by the number of parts needed for that period. The number of work hours is total time worked, less breaks and scheduled stoppage time. Account may also be given for breakdowns if an extended (i.e., monthly) value is calculated. Nominally, Takt time would be calculated on a weekly basis, as a day would be considered too short and a month too long (Bicheno, 2000). It is currently unknown by the researcher if maintenance is included with Takt time calculations within practical work environments. In particular, if maintenance activities beyond operator maintenance are even included with scheduled stoppage time.

The lean emphasis of Takt time is the customer, with the perceived benefit of achieving rate uniformity throughout a company and its supply chain. Qualitatively, the use of Takt time with maintenance included can be investigated through interviews, observations and case study pattern matching. Quantitatively, performance data may reflect the ability of the maintenance function to complete tasks within allocated time slots. Likewise, it may also be able to indicate mis-calculated Takt time allowance. For example, the number of maintenance jobs completed within a period may increase or level off, as a result of using Takt time, while the number of jobs still in hand for that period may decrease. Similarly, it may be that the time allowed for the maintenance jobs may not be enough to complete all tasks, if so, then the quantity of jobs in hand during that time may increase.

4.3.20 Value focused thinking

Similar in style and concept to scenarios, value focus thinking is a 'creative decision making process' (Bicheno, 2000). By working backward from a perceived future state, suggested guidelines and recommendations can be developed for medium and long-term future lean developments. The emphasis of this approach is to seek, support and understand variation in the long term, with a perceived benefit of aiding decision-making. What impact the approach to decision-making and long term planning has upon the maintenance function cannot be evaluated quantitatively. However, if this type of lean practice is used, then qualitative research may be able to identify its use by the maintenance function.

4.3.21 Supplier partnerships

'The concept of supplier partnerships developed as a result of the movement toward just-in-time manufacturing' (Bicheno, 2000). In common with lean thinking and its

approach to inventory, the philosophy of supplier partnerships is of co-operation rather than confrontation. It is aimed at reducing costs, delivery lead times, and waste through improved efficiency and communication. Bicheno (2000) also differentiates between what supplier partnerships are, and what supplier associations are. Supplier partnerships are where suppliers and end users form relationships for mutual benefit. Supplier associations are essentially an extension of supplier relationships, whereby suppliers form groups to increase competitive advantage and/or productivity through co-operation. Bicheno (2000) says that there are three types of supplier association: for operations, purchasing, and marketing. With regard to operations, the benefits would be to gain cost, quality and delivery improvements. An early example of supplier partnerships from a production quality viewpoint was provided by Womack and Jones (1994), who recount how Nissan UK turned their poor suppliers into better suppliers by integrating their supply and development department with them.

From a maintenance perspective, industries such as electronics, automobile and aircraft manufacturing are undertaking joint exploitation of service part inventories (Fortuin and Martin, 1999), with the intention of saving costs. Fortuin and Martin point out that some service collaboration may provide the opportunity to aggregate demand, and therefore reduce overall investment in parts. Put simply, their research suggests that supplier relationships and associations concerning spare parts requirement could be beneficial to both user and provider. In 2000, supportive case study research by Botter and Fortuin investigated a stocking strategy for service part inventories. This particular research focussed on logistics, storage, part classification, and level of service of one particular company to its service centres. How well their approach could satisfy client companies and their needs was not discussed however.

Another form of maintenance management that may possibly be termed or described as a form of supplier partnership is that of 'outsourced' maintenance. However, the issue of outsourcing maintenance can be highly subjective and will certainly vary between different organisations. Furthermore, in most situations where maintenance is outsourced, there will always be some form of service level agreement between the user and supplier in place, that will bind the amount, type and quality of work done.

Evidence suggests that there are possible benefits to be found through supplier partnerships. As such, case study research may be undertaken to understand fully the presence and usefulness of supplier partnerships between maintenance and suppliers. Qualitatively this may be found through interviews, observations and pattern matching. Quantitatively however, the lean emphasis of supplier partnerships, and the perceived benefit of cost reduction would be harder to substantiate in isolation. As such, it may be

that the use of non-maintenance based measures (e.g., accounting) could provide a clearer indication of the benefits of supplier partnerships within maintenance.

4.3.22 Open book management

Open book management aims for organisational transparency, greater employee management, literacy and homogeny. In terms of implementation, this is an objective approach to extend further improvement. Related by Bicheno (2000), open book management has four main principles, these are: sharing information (everyone has to know what is going on); business literacy (everyone needs to understand the numbers and to use them); empowerment (true responsibility); and lastly, a stake in the business. Its impact on the maintenance function can only be measured qualitatively in terms of how this approach is used and adopted within an organisation.

4.4 Development of a lean thinking reference framework

Case study analysis was proposed as the most appropriate and real-world centred methodology to investigate the research question: “How does lean thinking improve the effectiveness of the maintenance function”. Ideally for this research, a situation would exist whereby an agreed point of reference could be used to help determine the type of information required. However, the researcher could find no existing practical or commonly recognised method of reference to use, so an alternative approach had to be sought.

Without a suitable reference, a framework that can help investigate the research question was required. The primary purpose was that the framework satisfies both the case study design and the researcher’s requirements. Assumptions regarding the extent or use of lean concepts by maintenance within companies could not be made, so this researcher adopted the same principles as Comm and Mathaisel (2000): develop a strategy based on the connectivity between the links identifiable within a process and those that comprise lean thinking. The identifiable links with the process in this case were based on the standard definitions of maintenance and manufacturing systems. Understandably, not all eventualities concerning possible lean concept use could be used within the scope of this research.

Using waste elimination as the central theme of lean thinking, lean concepts were investigated for their lean emphasis and the possible perceived benefits to maintenance. By separating and discussing the lean concepts on their own merit, the researcher was able to investigate the characteristics more thoroughly to see if qualitative and / or

quantitative research can be used to support their use by maintenance. Figure 4.3 provides a summary of the concepts presented in the earlier sections:

Lean Concept	Lean Emphasis	Perceived Benefit	Possible sources Of information
5S	Participation	Improved asset Mtance	Qualitative
TPM	Prevention	Asset uptime	Qual'tive / Quan'tive
OEE	Improvement	Asset availability	Qual'tive / Quan'tive
Standards	Improvement	Standardised work	Qual'tive / Quan'tive
Mapping in general	Process	Task improvement	Qual'tive / Quan'tive
Process activity mapping	Time	Improved utilisation	Qual'tive / Quan'tive
Lead-time mapping	Time	Lead-time breakdown	Qualitative
Lean and inventory	Waste	Improved turnover	Qual'tive / Quan'tive
Visual management	Task visibility	Workforce involvement	Qualitative
Root cause problem solving	Improvement	Defect reduction	Qual'tive / Quan'tive
Continuous improvement	Gemba	Improved efficiency	Qual'tive / Quan'tive
Kaizen	Improvement	Waste reduction	Qual'tive / Quan'tive
Pokayoke	Prevention	Improved throughput	Qual'tive / Quan'tive
Self-audits	Visibility	Self-evaluation	Qualitative
Storyboarding	Visibility	Information access	Qualitative
Kanban	Pull	Task control	Qual'tive / Quan'tive
Scenarios	(Decision) Pull	Organisational learning	Qualitative
Takt time	Customer	Rate uniformity	Qual'tive / Quan'tive
Value focused thinking	Variation	Aid decision making	Qualitative
Supplier partnerships	Partnership	Cost reduction	Qualitative
Open book management	Partnership	Ownership	Qualitative

Figure 4.3 Lean thinking framework reference summary

In Figure 4.3, it can be seen that each concept may be investigated qualitatively but not all the issues can be investigated quantitatively. Nonetheless, although additional clues may be sought through quantitative means, these can only be used to support or question any qualitative findings from data collected by those companies being investigated.

Overall, the approach taken for this particular area of research has satisfied a fundamental criterion of case study design in addition to the needs of this researcher. Consequently, the following chapter presents, discusses, and justifies a suitable method of quantitative research that can be used to support investigation where possible, of the research question more substantially.

4.5 Chapter summary

This chapter presented and discussed the development of a lean thinking reference framework. The basis of the framework was developed from the need to satisfy a basic rule of case study design for investigation, and this researcher's requirement to investigate the research question: "How does lean thinking improve the effectiveness of the maintenance function?"

The intention of the lean reference framework is to represent lean thinking concepts possible within a company and maintenance in particular, and use it as a basis for further research. By separating the issues and discussing their use, lean emphasis and the perceived benefits possible through practice, their suitability for qualitative and or quantitative research could be sought.

As no previous example of a lean reference framework could be found or used for this research, different approaches for the implementation or use of lean concepts within companies were investigated. Based on the standard definition of maintenance, manufacturing systems and using waste elimination as the central theme of lean thinking, one particular approach was used as a reference to develop the lean thinking reference framework.

Overall, the lean thinking framework provides a way of indicating what information should be sought, and what needs to be done once the data or information has been collected.

Chapter Five

Maintenance performance indicators

5.1 Introduction

This chapter presents and discusses the development of an overall measure of maintenance performance that includes a number of performance index ratios. The use of these ratios is to identify change within maintenance effectiveness through activity, and this is discussed below. Figure 5.1 provides a schematic representation of the structure of this chapter:

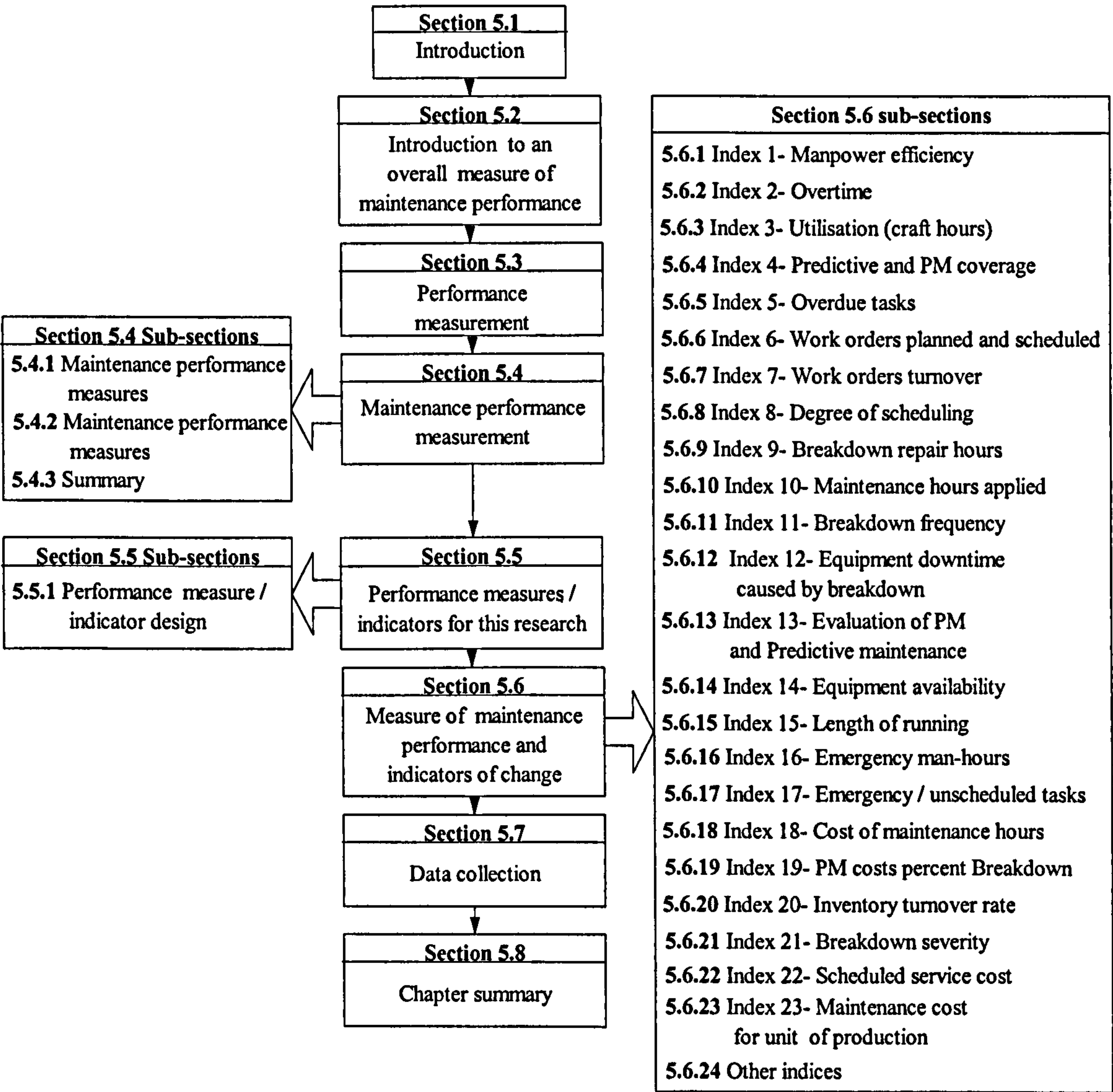


Figure 5.1 Layout of chapter five

5.2 Introduction to an overall measure of maintenance performance

Chapter four presented and discussed the development and use of a lean thinking reference framework to reflect the lean thinking concepts possible within a company and maintenance in particular. The aim of this particular chapter is to present a methodology that will provide additional quantitative support to the investigation process.

The literature review showed that maintenance performance measures for various lean activities have been developed, but these measures although beneficial as monitors, are either not suitable as sole performance measures or require further research. Therefore, in order to identify if aspects of lean thinking improve the effectiveness of the maintenance function, appropriate performance indicators need to be identified. However, before any choice of indicator is made, the literature on the theory and use of performance measurement has to be considered.

The following sections present and discuss the issues of performance measurement, and development of measures of maintenance performance that include suitable indicators for this research. Data collection techniques are also discussed.

5.3 Performance measurement

A great deal of literature and examples exist concerning the use of performance measurement. For example, Neely (1999) states that between 1994 and 1996 alone, there were 3615 articles on performance measurement concerning mostly business methods. This is despite the fact that most of the basic business methods of performance measurement for big companies had already been in place since 1910 (Neely, 1999). The importance of performance measurement to business cannot be underestimated and does require discussion here.

✓ Performance measurement is the process of quantifying action, or rather the efficiency and effectiveness of action. The terms effectiveness and efficiency refer to the extent to which customer requirements are met (effectiveness) and how economically resources are utilised to provide a given level of customer satisfaction (efficiency) (Neely *et al.*, 1994; 1995). ✓

Neely *et al.* (1995), in their in-depth literature review of performance measurement and systems design, suggest that there are essentially three types of performance measure, which are descriptive, reactive and predictive. Descriptive measures are used to monitor

past performance, and reactive and predictive measures are those that stimulate future action. The main reasons for interest in the use of business performance measurement are possibly due to the changing nature of work, increased competition, specific improvement initiatives, changing organisational roles, changing external demands, and the power of information technology (Neely, 1999). Preceding this, Sink (1985) considered the underlying intent or motive of performance measurement to be control, prediction, estimation, decision making, and problem solving.

The considerable interest in performance measurement stems from initial dissatisfaction with financial measures used in the 1970s and 1980s. In particular, Johnson and Kaplan (1987) felt relevance was lost between the 1950s and 1980s when management used cost based accounting methods, which they felt encouraged short termism and minimal variance to control operations, rather than continuous improvement. They were not alone in their criticisms of the perceived shortcomings of cost accounting systems, and newer methods of performance measurement were developed. Fundamentally, these type of measures focus on issues less financially biased and more in keeping with the emphasis of quality, JIT, and continuous improvement.

The basis for the newer style of performance measurement discussed above is that improvements in non-financial measures drive the financial performance of the company (Kaplan and Norton, 1992; 1996). The “balanced scorecard” (probably the best known framework) focuses on four aspects of performance measure capable of ‘telling the story’ within an organisation that need to be addressed. These are financial, customer oriented, business oriented, and learning and growth (Kaplan and Norton, 1992; 1996). For manufacturing and operations based companies, measurement is focussed on the central issues of the business which are usually cost, quality, delivery, people, suppliers, markets and new product introduction (Bicheno, 2000).

The design of a performance measurement system is principally a cognitive exercise which translates the views of the customer and stakeholder’s needs into business objectives and appropriate performance measures (Bourne *et al.*, 2000). Developed by Bicheno (2000), Figure 5.2 represents a variation of the balanced scorecard model by identifying six groups of necessary measures, as opposed to the original four aspects as discussed above:

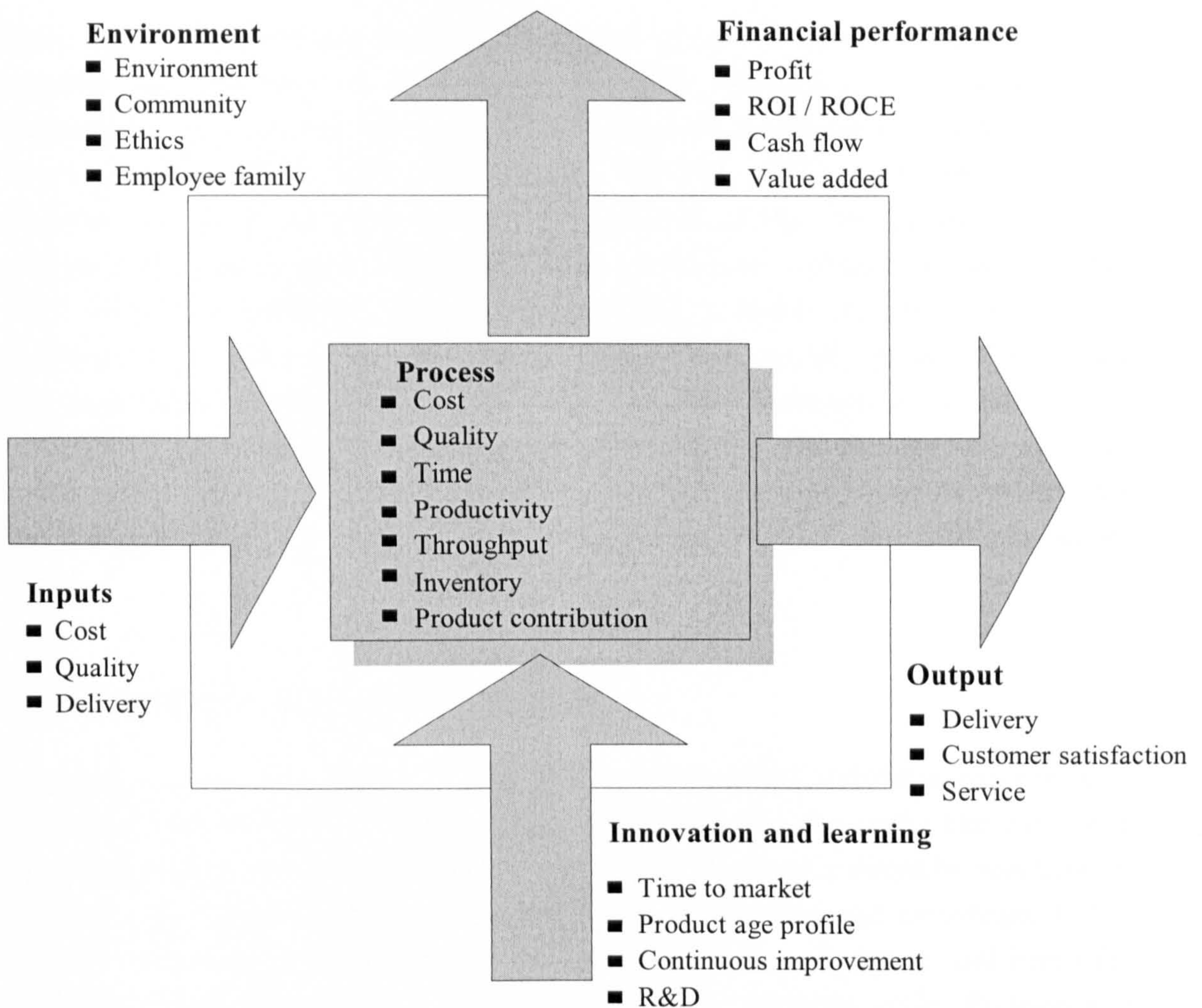


Figure 5.2 Six starting points for performance measure (Bicheno, 2000)

Although considered important, there has been a lack of research into the practical use of performance measurement systems outside of academic interest. Also, from a practical point of view, the implementation of measurement systems that require redistribution of information generally meet with resistance from senior managers who feel threatened by the erosion of their power base (Bourne *et al.*, 2000). Johnson (2000) conveys the message that performance measurement is important, but there is no common definition for a performance measurement system especially within the literature. Essentially, the performance measure frameworks that do exist, do not offer specific advice to companies on the process of developing or implementing performance measurement, but do encourage a balanced view of how they should be used.

5.4 Maintenance performance measurement

Performance measurements are used to indicate where a business is and where it is heading, and functions as a guide to achieving business goals. Likewise, for maintenance as a function integrated within a business, performance reporting is also important (De Groote, 1995; Pintelon and Puyvelde, 1997). More specifically to illustrate the position, progress and effectiveness of the maintenance function, performance measurements should if possible, reflect all relevant consequences that affect performance (Niegel, 1994; Armitage, 1970). It should also be noted that any choice of action concerning performance measurement generally should fulfil at least two fundamental criteria. Firstly, all actions should be viewed in relation to the organisation, and satisfy the requirements of the decision-maker. Secondly, all other requirements although desirable, can be regarded supplementary to these two requirements (Neely *et al.*, 1994; 1995; Bourne *et al.*, 2000; Niegel, 1994; Armitage, 1970).

5.4.1 Maintenance performance measures

In isolation, many maintenance performance measures satisfy individual requirements, but collectively they seldom if ever, satisfy all the properties of a performance measure (Armitage, 1970). Accepting that some measures of performance would be beneficial, it is necessary to decide what direct measures and or indices to use (Armitage, 1970). Various index-based methods for measuring maintenance performance, and hence for controlling maintenance effort, have been developed (Armitage, 1970; Pintelon and Puyvelde, 1997; Kutucuoglu *et al.*, 2001). However, examples of organisations that have used them are difficult to find (Kelly, 1997), or they require further development and research (Kutucuoglu *et al.*, 2001).

To sustain high maintenance efficiencies, trend reports based on performance measurements are needed. Any measurement standing by itself is seldom significant, and so it must be compared with something (Niegel, 1994). Kelly (1997) suggests the use of a cost effectiveness index comparing overall maintenance costs against manufacturing output, whereas others (Armitage, 1970) indicate a number of desirable aspects that measures of maintenance performance should possess. For example these aspects should:

- 1 Be easy to calculate with simple metrics
- 2 Be easy to interpret and so therefore be straightforward

- 3 Reflect subjective management notions of what constitutes maintenance performance, in that they satisfy the requirements of the decision-maker
- 4 Indicate the need for remedial action and therefore be reactive
- 5 If possible, reflect all relevant consequences that affect performance and be as comprehensive as possible

Pintelon and Puyvelde (1997) argue that maintenance performance will depend on the perspective applied. For example, accountants and top management will often think of maintenance in terms of cost, engineers will tend to focus on techniques, and production will focus on equipment availability. These arguments are reflected in industry, as companies will generally have different reasons for implementing performance measurement. They are also more-or-less representative of the reasons provided by various authors in their development and choice of measures and indicators for maintenance performance (De Groote, 1995; Kutucuoglu *et al.*, 2001).

5.4.2 Evaluation of maintenance performance measures

Pintelon and Puyvelde (1997) assessed various aspects of maintenance performance and advocated the use of a 'maintenance management tool' (MMT) to evaluate performance over short periods. This 'quick evaluation' forms the basis of detailed reports used to diagnose problems within maintenance and suggests possible appropriate remedies. Other types of maintenance performance measure focus on the use of quality audit assessments to develop maintenance performance indicators (De Groote, 1995); the use of a balanced scorecard approach that links with organisational strategy- (Tsang, 1998; Tsang *et al.*, 1999); and quality function deployment (QFD) (Kutucuoglu *et al.*, 2001).

The type and use of performance measures as discussed above reflects what the authors feel is representative of a suitable method for measuring maintenance performance. Japanese methods of performance measurement such as OEE are perhaps more readily available, understood, and used (Kelly, 1997; Nakajima, 1988). In addition, the general issue with OEE is that although beneficial as a production monitor, it is subject to the quality of data collected, where maintenance is only one effect among several (Sherwin, 2000). It is important therefore, that it does not become the sole performance measure for this reason (Jeong, 2001; Dal *et al.*, 2000).

Focussing specifically on maintenance issues, Niebel (1994) presents a number of indices assigned to three categories related to the maintenance function: administration, effectiveness and cost. Similarly, Corder (1963), Priel (1962) and Luck (1956) also demonstrate alternate indices and index based methods for measuring performance.

Corder (1962) surmises that one index can be a suitable measure of maintenance efficiency. He recommends that by comparing the value of this index yearly, based on total maintenance costs incurred, lost time and waste produced, the decision-maker can appreciate whether the efficiency of the maintenance function has improved or diminished for that period.

The focus for Priel (1962; 1974) is to concentrate on three major maintenance evaluations:

- 1 The effectiveness of maintenance - is maintenance being fully utilised, and are its efforts effective?
- 2 The amount of maintenance - is the service provided by maintenance adequate?
- 3 The cost of maintenance - are costs commensurate with results achieved?
- 4 Priel's approach to maintenance performance involves a large number of indices that escalate to one overall index. The perceived advantage of Priel's approach is that some account is made of relevant variables within maintenance that can provide clues or indication of change through activity.

Luck (1956), although pre-dating Priel and Corder, combines a number of indices involving various performance variables to provide a single measure of maintenance performance. These are based on workload, planning, cost and productivity. The perceived advantage for Luck is that a large number of consequence variables can be used without the added difficulty of interpreting an overall effectiveness value (Armitage, 1970).

5.4.3 Summary

The literature shows that different performance reporting methods exist to match the needs or requirements of the particular proponents of such measures. Individually, some forms of measure account for the organisational aspect of maintenance within a

business, others focus on particular operational aspects. The issue for this particular area of research is to seek suitable performance measures / indicators within maintenance, that through activity may possibly relate to the use of certain lean concepts. These issues are discussed below.

5.5 Performance measures / indicators for this research

The development and use of maintenance performance measures within this research cannot be without regard to the diversity of the maintenance organisations under investigation. Other issues that need to be understood and taken account of are the general guidelines of what a measure of performance or indicators of change should consist of.

The need of this research is to seek descriptive maintenance data recorded by active organisations; especially those data that may relate to lean concept use by maintenance. Understandably, a common sense approach would be to use or develop specific indicators that relate directly to the use of lean techniques by maintenance. However, although the use of lean indicators in the form of checklist assessments have been developed (Sanchez and Perez, 2001) these only reflect perceived lean production issues, for example production indicators of continuous improvement, indicators of JIT production and delivery, rather than maintenance effectiveness.

5.5.1 Performance measure / indicator design

Complexity of the maintenance function often makes it difficult to develop causal relationships between managerial decisions and overall success or failure of maintenance systems (Kutucuoglu *et al.*, 2001). This may be because previously, many companies just measured their maintenance performance in terms of small-scale budget reporting. Alternatively, it may be due to the long time failure of both practitioners and academics to recognise maintenance management as a business function (Pintelon and Puyvelde, 1997). Furthermore, as maintenance is primarily a logistics function integrated into production processes, it can only really be appreciated in terms of relative performance ratios rather than absolute values of efficiency (Priel, 1962; De Groote, 1995).

Although indicators in the form of ratios are commonly used and appeal to different performance hierarchies within maintenance, for instance cost, task, and efficiency, it is difficult to identify the specific hierarchies in which they belong (Kutucuoglu *et al.*, 2001). As discussed earlier, good practice would insist that not only are the

requirements of the decision-maker (i.e., the researcher) satisfied, but also actions that relate to performance should also relate to the business or organisation as well. Nonetheless for this research, the requirement of using indicators of change through action need only be representative of direct maintenance activities, rather than an overall measure of maintenance performance.

As a function, maintenance is considered too complex to rely on just one or two performance indexes as a reliable basis of control. To get the correct composite picture you have to appraise the facets that have tangible indicators, and derive indexes of effectiveness for each one. Once compiled, their trends should blend together to form a picture in which conclusions will emerge (Priel, 1962; 1974). Put simply, develop indicators of ground level changes, and then escalate through indexes to an overall measure of maintenance performance that provides a strategic view of the maintenance contribution. However, the way to build an adequate performance reporting system for maintenance is not obvious (Pintelon and Puyvelde, 1997). Then again, it is not that obvious for performance measurement systems generally either. As discussed by Johnson (2000), good performance measurement systems do not just happen, they are designed. They take a considerable amount of time and effort to develop, implement, improve and be accepted.

Taking into account that fundamentally ‘performance measurement is a means to an end, and not an end in itself’ (Neely *et al.*, 1996), the researcher has used a combination of performance techniques principally prescribed by Priel (1962; 1974) and Niebel (1994). The contribution of these measurement techniques is that they are perceivably practical approaches to maintenance performance that satisfy the needs of this researcher. They are modular in construction, easy to understand and can provide an overall measure of maintenance performance in relation to an organisation if need be. If data are available, the indices themselves are relatively easy to calculate and interpret, can indicate the need for remedial action, and where possible, reflect the relevant consequences that effect performance, and management notions of what constitutes maintenance performance.

The following section is used to present and discuss the indicators used to identify change through maintenance activity and their significance. These are viewed within the context of an overall measure of maintenance performance developed by the researcher.

5.6 Measure of maintenance performance and indicators of change

[To develop an effective measure of performance, four basic questions need to be asked: why measure; what to measure; where to measure; and how to measure? (Oakland, 1995).] Largely, each of these questions has been answered previously. The emphasis here is to focus on the use of performance indicators for this research. The indicators are included within an overall measure of maintenance performance, usable by those with different policy approaches to maintenance. The overall measure itself is not the focus of this research.

The development of an overall measure of maintenance performance is primarily to ensure that good practice and understanding are followed. The simple modular structure of the framework does not restrict its use or level at which it can be used within a maintenance organisation, should data be available. In general terms, the overall measure is able to provide the business with an indicator of overall maintenance performance, [while allowing frontline maintenance to obtain immediate medium and long-term feedback of their activities. In particular, those activities that possibly relate to lean concept use.] In practical terms however, it is unlikely that any one company would make use of, or record all the indices within the overall performance measure. The simple reason being that the overall measure has been designed to be fully comprehensive to compensate for the different types of maintenance function under investigation. It has also been developed to accommodate the different methods and style of maintenance data collection by those under investigation.

A top-down approach, with the overall measure cascading through subsequent indices to individual indicator indexes allows the business to assess the performance of the maintenance function. As the framework is hierarchical and simple, business managers should be able to drill-down to identify root cause changes within the indices they use. Escalation from the indicator indexes will not only provide frontline maintenance feedback on their activities, but will also provide a clear perspective of how they are being used by the business.

[Figure 5.3 highlights the overall measure of maintenance performance developed for this research. The following sub-sections introduce and explain the indicator indexes usable for the possible measurement of maintenance performance.]

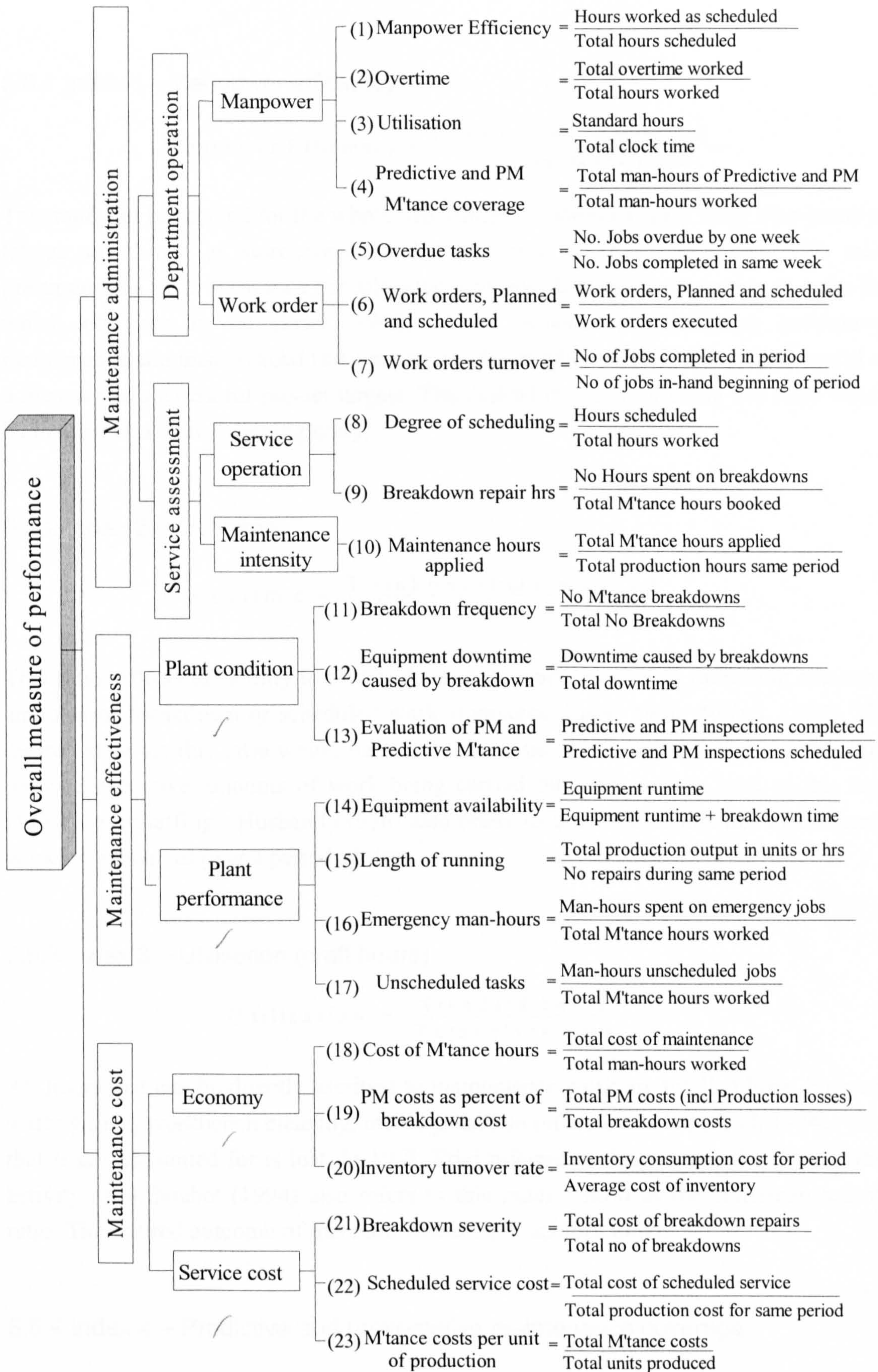


Figure 5.3 Overall measure of maintenance performance

5.6.1 Index 1 - Manpower efficiency

$$\text{Manpower Efficiency} = \frac{\text{Hours worked as scheduled}}{\text{Total hours scheduled}}$$

This ratio can be applied for the whole department, or for each craft. Only man-hours of labour are shown as storekeeping and supervision are not considered. This ratio presupposes a time allowance for allocated jobs and does not really apply to tasks for which no time is set (Priel, 1962; 1974). Nonetheless, excluding breakdown maintenance and unscheduled tasks accounted for in other indices, this ratio is useful as a measure of success for pre-set targets. The desired outcome of using this ratio would be to achieve a value reaching unity.

5.6.2 Index 2 – Overtime

$$\text{Overtime} = \frac{\text{Total overtime worked}}{\text{Total hours worked}}$$

This ratio reflects the ability to plan and schedule work, as well as indicating excessive amounts of breakdown or scheduled work stoppages (Luck, 1956; Niebel, 1994). The desired state for this ratio would be a constant value, that is not too high, as this may indicate excessive amounts of work being carried out, and not too low, as this may indicate overstaffing. Husband (1976) also refers to this ratio to monitor maintenance workforce changes over a period of time.

5.6.3 Index 3 – Utilisation (craft hours)

$$\text{Utilisation} = \frac{\text{Standard hours}}{\text{Total clock time}}$$

All hours that can be directly ascribed to maintenance work are totalled here. Enforced waiting time, workbench cleaning, meetings and so on are excluded (Priel, 1974). Time that is not accounted for is lost. In 1962, Priel referred to this ratio as the craft worker activity ratio. Niebel (1994) also refers to this index / ratio as the craftsman activity ratio. The desired outcome of this ratio would be to achieve unity.

5.6.4 Index 4 – Predictive and preventative maintenance coverage

$$\text{Predictive and PM M'tance coverage} = \frac{\text{Total man-hours of Predictive and PM}}{\text{Total man-hours worked}}$$

This ratio is used to assist better planning and scheduling of required maintenance work (Niebel, 1994; Husband, 1976). Luck (1956) expresses this ratio as the percentage ratio of the total man-hours per month for preventative maintenance. The desired outcome of using such a ratio is that it can signify positive or negative impact changes. Too high, and the ratio needs to be reduced to an acceptable level then stabilised, too low, and the ratio needs to increase to reach stability. From a lean production perspective this ratio is also referred to in terms of percentage of preventative maintenance over total maintenance as a contributor to 'zero value activities' (Sanchez and Perez, 2001). The recommendation is that the percentage value should increase in order to progress to lean production. From this researcher's point of view, this is not entirely right, as too much PM is also a waste.

5.6.5 Index 5 – Overdue tasks

$$\text{Overdue tasks} = \frac{\text{No. Jobs overdue by one week}}{\text{No. Jobs completed in same week}}$$

This ratio is used to show whether jobs are getting prompt attention or not. It is also useful when an attempt is made to pin production delays on slow maintenance (Priel, 1962). In 1974, Priel referred to this ratio as 'completion delays'. For completion delays, all incomplete jobs including those in-progress and pending, are multiplied by the respective number of weeks they have been outstanding. By dividing this figure by the total jobs handled in an average week, a delay value is then given. A value of less than one would indicate a delay of less than one week until completion, whereas values above two would require action (Priel, 1974). However, distortion could be possible if smaller jobs were handled first thereby reducing the overdue value quickly, but this is not altogether advantageous. Logically, small jobs would normally be fitted in between larger ones or act as fill in work for larger jobs.

In similarity to the overdue tasks ratio are those adopted by Luck (1956) and Niebel (1994), who both refer to 'crew weeks of current backlog' and 'crew weeks of total backlog'. Crew weeks of current backlog is defined as the work scheduled ready to release in man hours is divided by a crew week. Subsequently, crew weeks of total backlog is where the total man hours of work awaiting execution is divided by one crew week in man hours.

The emphasis of Luck and Niebel's ratios is primarily to anticipate or correct craft imbalances. Understandably, a desired outcome of using the overdue tasks (e.g., average delay) ratio for improvement checks would be a diminishing value. However, if the

tasks to completion ratio falls to a level too low for too long, then it may be that not enough jobs are being issued.

5.6.6 Index 6 - Work orders planned and scheduled

$$\text{Work orders Planned and scheduled} = \frac{\text{No. Work orders, Planned and scheduled}}{\text{Work orders executed}}$$

This ratio is used to focus on the ability of maintenance to focus and manage its jobs (Niebel, 1994; Luck 1956). Typical work order examples could be rework tasks resulting from maintenance inspections. For an improvement or change program the desired outcome for this ratio would be to aim for unity.

5.6.7 Index 7 - Work orders turnover

$$\text{Work orders turnover} = \frac{\text{No of Jobs completed in period}}{\text{No of jobs in-hand at present}}$$

This ratio relates to work orders representing individual requests, such as repairs, improvements, transfer or installation of equipment. It does not refer to predictive or preventative maintenance activities, or other cyclic tasks. The denominator is made up of all the orders that are 'in-hand' at the start of a period. It is the widening gap between this value and the jobs completed that will indicate change. Although a rising number of incoming requests may not necessarily reflect badly upon maintenance performance, it may still indicate a low effectiveness. Similarly, an alarming rise in the number of incoming orders may raise the suspicion that people are bothering maintenance with petty requests. A low turnover on the other hand may indicate that maintenance is unable to cope efficiently with its workload (Priel, 1962; 1974). Husband (1976) highlighted the same ratio and notes that sometimes it is difficult to differentiate between major projects, or capital work and relatively insignificant repair orders.

5.6.8 Index 8 - Degree of scheduling

$$\text{Degree of scheduling} = \frac{\text{Hours scheduled}}{\text{Total hours worked}}$$

For ease of understanding and interpretation, this ratio relates to Priel's (1974) routine services workload ratio. The total hours worked value is the sum of hours spent on regular services, repairs, overhauls, plant expansion and workshop rework jobs, etc.

Unassigned time (i.e., waiting time) between jobs cannot be charged to any job so these are accounted for in the difference between hours scheduled and total hours worked.

5.6.9 Index 9 - Breakdown repair hours

$$\text{Breakdown repair hrs} = \frac{\text{No Hours spent on breakdowns}}{\text{Total M'tance hours booked}}$$

This ratio serves as a guide to whether inadequate maintenance or poor skills of operation, age and / or condition of plant are to be blamed for the number of hours spent on breakdowns. It is used to indicate the effectiveness of prevention and the need to shorten breakdown time through better communication, transportation, spare-parts control, or on the spot availability (manpower, resources etc.) (Priel, 1962; 1974). The desired outcome of using this trend (reflective of the values from indexes 16 and 17, below) would be a low or diminishing value.

5.6.10 Index 10 - Maintenance hours applied

$$\text{Maintenance hours applied} = \frac{\text{Total M'tance hours applied}}{\text{Total production hours same period}}$$

Initially called the 'craft manpower requirement' in 1962, and 'maintenance to production hours ratio' in 1974 (Priel, 1962; 1974), this ratio is essentially an indicator for maintenance service that is provided. It is used to express the amount of maintenance hours that are spread over production hours. Put simply, it may be used as a measure to find the right number of maintenance hours against a varying degree of plant operation. The denominator may also be expressed in machine utilisation hours (Husband, 1976). Overall, once established this ratio should either decrease or remain stable.

5.6.11 Index 11 - Breakdown frequency

$$\text{Breakdown frequency} = \frac{\text{No M'tance breakdowns}}{\text{Total No Breakdowns}}$$

This (maintenance) breakdown frequency ratio is used to highlight poor maintenance, i.e., number of breakdowns caused by poor maintenance (Priel, 1962). As a value the desired outcome would always be close to zero, and is not inclusive of stoppages to avoid scrap or material wastage as these are considered production penalties.

5.6.12 Index 12 – Equipment downtime caused by breakdown

$$\text{Equipment downtime caused by breakdown} = \frac{\text{Downtime caused by breakdowns}}{\text{Total downtime}}$$

This is one of four ratios used by Niebel (1994) to help determine maintenance effectiveness. The importance of this ratio is to help understand the characteristics of equipment failures so that corrective action can be focussed in the right areas. Similar to index 11 this ratio should aim to zero.

5.6.13 Index 13 – Evaluation of PM and Predictive maintenance

$$\text{Evaluation of PM and Predictive M'tance} = \frac{\text{Predictive and PM inspections completed}}{\text{Predictive and PM inspections scheduled}}$$

This ratio is the second of four ratios used by Niebel (1994) to help determine maintenance effectiveness. It is also similar to Index 4. Whereas Index 4 is primarily used to determine or control task hours of predictive and preventative maintenance coverage, this ratio focuses on the tasks conducted. The target aim for this ratio is unity and may be used to indicate change fluctuations of improvement initiatives.

5.6.14 Index 14 - Equipment availability

$$\text{Equipment availability} = \frac{\text{Equipment runtime}}{\text{Equipment runtime} + \text{breakdown time}}$$

The full title of this ratio is 'Equipment mechanical availability', and was introduced by Priel in 1962. Various forms of this ratio are also used. Perhaps the most commonly known and used is the availability index provided by Nakajima (1988) within his OEE calculations. Husband's (1976) recommendation was to use production-operating time divided by production-operating time plus downtime as a measure of the availability 'of crucial bottleneck equipment'. De Groote (1995) suggested the ratio should reflect the number of gross operating hours divided by the gross operating hours plus downtime for maintenance (planned and unplanned). However, the emphasis of this ratio is that it does not penalise maintenance for non-running time caused by production delays.

5.6.15 Index 15 – Length of running

Length of running = $\frac{\text{Total production output in units or hrs}}{\text{No repairs during same period}}$ *Air lines or Comm*

In 1974, Priel replaced the original (maintenance) breakdown frequency ratio (see index 11) and this ratio term (termed ‘average running period between repairs’) from 1962 and termed it ‘breakdown frequency’ (Priel, 1974). However, it is useful for this research to keep the ratios separate as they were in 1962, hence index 11 and this index 15. This ratio is used to reveal the quality and adequacy of servicing by showing whether added service in hours, parts or higher frequency gives noticeable results. Husband (1976) also relates to this ratio, but with less explanation. Nonetheless, for a more in depth perspective of the repair causes, further investigation will be needed. Initially, the application of this ratio was intended for continuous throughput environments (pumps, mills), or, where large groups of similar machines are used. However, there is no objection to counting all the mechanical units and multiplying them with shift hours to use as the numerator. Obviously, the larger the value of this index, the less trouble you have.

5.6.16 Index 16 – Emergency man-hours

Emergency man-hours = $\frac{\text{Man-hours spent on emergency jobs}}{\text{Total M'tance hours worked}}$

This ratio is the third of four ratios used by Niebel (1994) to help determine maintenance effectiveness. This ratio is related to Index 9 in that it contributes to its numerator. Essentially this ratio represents all jobs that appear unexpectedly and are deemed urgent. It is separated by the following index (17) in that it focuses specifically on emergency issues that prevent production (i.e., production stoppage time). Similarly, Husband (1976) relates more to this ratio in terms of man-hours of emergency jobs rather than Index 9, which it may have been intended for. Although Husband uses the term total man-hours on breakdown work as a numerator, his description of breakdown work suggests that breakdowns are those that prevent production. However, in likeness to Index 9 he suggests that this ratio be used to justify the need for decentralised maintenance in specific areas of a plant. As with Index 9, the desired outcome of using this trend would be a low or diminishing value.

5.6.17 Index 17 – Emergency and other unscheduled tasks

Unscheduled tasks = $\frac{\text{Man-hours unscheduled tasks}}{\text{Total M'tance hours worked}}$ — *UnSch Removal
Sch Removal*

This is the fourth of four ratios used by Niebel (1994) to help determine maintenance effectiveness, and represents the tasks that appear unexpectedly and require repair. Although the tasks may be classified as urgent, they are not generally those that prevent production. As with Index 9 and Index 16 above, the desired outcome for this trend would be a low or diminishing value.

5.6.18 Index 18 - Cost of maintenance hours

$$\text{Cost of Maintenance hours} = \frac{\text{Total cost of maintenance}}{\text{Total man-hours worked}}$$

This ratio is referred to by Priel (1962; 1974), and Niebel (1994) as part of maintenance costs. Although this ratio is used to provide a general cost per hour for any given time period, its use can provide additional scrutiny for improvements. Improvements that reveal the effects of better management of manpower (e.g., increased amount of planned regular work) and economic performance of activities. However, this ratio is only a general guide for the cost of maintenance hours and can be influenced by the overhead composition of certain jobs including labour and materials over or under estimation.

5.6.19 Index 19 – PM costs as a percent of breakdown cost

$$\text{PM costs as percent of breakdown cost} = \frac{\text{Total PM costs (incl Production losses)}}{\text{Total breakdown costs}}$$

This ratio by Niebel (1994) relates to the efficiency of the preventative maintenance program. Where the effect of preventative expenditure for selected items of equipment or, on the amount of emergency / high priority work can be observed. The production losses within the ratio refer to the costs due to lost production because primary equipment is down. The desired outcome of this ratio especially for an improvement program would be a diminishing value.

5.6.20 Index 20 – Inventory turnover rate

$$\text{Inventory turnover rate} = \frac{\text{Inventory consumption cost for period}}{\text{Average cost of inventory}}$$

As a yearly ratio (Niebel, 1994; De Groote, 1995) this provides a general guide of the stock rotation (i.e., the number of times the value of the stock is issued). Importantly, inventory levels should be monitored to maintain and improve reasonable levels of

financial control while avoiding ‘stockout’. From a lean production perspective, Sanchez and Perez (2001) suggest that to progress to lean production, inventory turnover should increase. Husband (1976) states in a similar ratio (i.e., cost of maintenance materials used divided by total cost of stock currently in the maintenance stores) that a ratio of this kind is an attempt at assessing the level of stocks of spares in the maintenance stores.

5.6.21 Index 21 – Breakdown severity

$$\text{Breakdown severity} = \frac{\text{Total cost of breakdown repairs}}{\text{Total no of breakdowns}}$$

This ratio by Priel (1962) and Husband (1976) is related to index 11 in that it supports the need for remedial action or reflects improvements through the use of other ratios.

5.6.22 Index 22 – Scheduled service cost

$$\text{Scheduled service cost} = \frac{\text{Total cost of scheduled service}}{\text{Total production cost for same period}}$$

This ratio is used to demonstrate the value of scheduled services (Priel, 1974). The aim here, with a modest rate of expenditure on ‘regular services’ (e.g., preventative maintenance), reductions in other areas of the maintenance domain will be more visible. Once a saturation point has been reached, further expenditure on this type of service may not lead to a decrease in other costs; this point is the level of service cost. A certain amount of equipment can only take so much scheduled service, and service beyond that figure should be carefully controlled as it may represent over-maintenance. Put simply, what is achieved in return for the money spent on machines?

5.6.23 Index 23 – Maintenance costs for unit of production

$$\text{Maintenance costs per unit of production} = \frac{\text{Total Maintenance costs}}{\text{Total units produced}}$$

This ratio by Priel (1974) serves those companies sensitive to the cost of maintenance and provides an insight to the escalation of maintenance costs. It specifically asks ‘what are the maintenance costs to produce one unit of product?’ In situations where maintenance costs are rising considerably, a breakdown of the possible causes is needed to discover the roots of the problem. Luck’s (1956) variation of this index is described as ‘the recent decrease or increase on maintenance cost per unit of product produced

over a base period'. Whereas De Groote (1995) uses the ratio of 'direct costs of maintenance divided by the added value of production'. By added value of production, he refers to the total cost of production less the cost of raw materials.

5.6.24 Other Indices

The indicator indexes, as used for measurement of maintenance performance, are designed to compensate for different types and varying methods of data collection used. Nevertheless, it is unreasonable to expect the performance measures and index ratios to accommodate all eventualities. Already present within the overall measure is the capability to generate further index ratios if required. Also, should the need arise, modularity and flexibility of design allows the inclusion of more index ratios to be included without interruption of the overall measure.

The inclusion of additional ratios within the overall measure is quite straightforward if needed. For example, some companies and their maintenance departments may use contract labour, so they may then also measure their contribution. Similarly, the use of a cost of supplies and spares ratio may be favoured by some as a more thorough approach to assessing or supporting inventory control. The use of an inventory ratio can easily be included alongside, or instead of Index 20 – Inventory turnover rate. De Groote (1995) suggests such a ratio as 'the total store issues and direct purchases divided by the total direct maintenance cost'. The contract labour cost ratio proposed by De Groote is the cost of subcontracting (manpower) divided by the direct cost of maintenance.

An example of how derivations for additional information can be obtained from the index ratios is given here. Index 14 - Equipment availability, is the equipment runtime divided by the equipment runtime plus breakdown time. Availability is the probability that a facility scheduled for service will be operating at any point in time, and is related to reliability and maintainability for system effectiveness (Niebel, 1994). It is obvious therefore, that Index 14 can only provide basic information, as anything more specific would require reliability and maintainability ratios to be used. In its basic form, reliability can be measured by the mean time between failure (MTBF) and maintainability by the mean time to repair (MTTR). For MTBF the ratio is the total operating hours divided by the number of breakdowns, for MTTR the ratio is the sum of all repair times divided by the number of breakdowns (Husband, 1976). Should the need arise and more specific information is required, then the ratio of MTBF divided by MTBF plus MTTR (Niebel, 1994) can be used to determine availability. To obtain more in-depth information regarding availability, system effectiveness, reliability and

maintainability would require more scientific methods of analysis, beyond the scope of the indices and overall measure presented and discussed here.

Beyond the scope of the overall measure of performance and indicator ratios are issues that concern health and safety, and environmental issues. Although consideration of their importance to the maintenance function cannot go unnoticed, these are parallel control issues strictly governed by legislation.

Based on three criteria: ease of data retrieval, cost of retrieval and ease of understanding the results, a spreadsheet application is used to calculate an output for the performance indicators used for this investigation. The following section presents and discusses the method of data collection and analysis used to compile the data from those maintenance organisations investigated.

5.7 Data collection

The use of the overall measure of maintenance performance and the indicators therein are wholly dependent upon the type of maintenance data collected by an organisation. The following storyline of screenshot figures, with explanations, depicts the process stages of data collection and how the data are processed. The development and use of a spreadsheet application by this researcher is to improve the data management and reliability of this research.

Stage One: Collect raw data from company

	A	B	C	D	E	F
1	Job No ▼	Type ▼	Planned▼	Comple▼	Status ▼	Work ▼
2	208959	WRECPLAN	02/01/01	?	WSTACAN	0
3	208960	WRECPLAN	04/01/01	26/01/01	WSTACOM	240
4	208961	WRECPLAN	02/01/01	?	WSTACAN	0
5	209212	WRECREAC	02/01/01	02/01/01	WSTACOM	30
6	209213	WRECWKSH	02/01/01	02/01/01	WSTACOM	0
7	209214	WRECREAC	02/01/01	02/01/01	WSTACOM	45
8	209215	WRECREAC	02/01/01	02/01/01	WSTACOM	30
9	209216	WRECREAC	02/01/01	02/01/01	WSTACOM	450
10	209217	WRECWKSH	02/01/01	02/01/01	WSTACOM	60

Figure 5.4 Example of maintenance data collected from company

Stage Two: Categorise collected data

	A	AM	AN	AO	AP	AQ	AR
1	CMMS OUTPUT	2001					
2	1998 - 2001	Feb	Mar	Apr	May	Jun	Jul
3	Planned PM Jobs	318	269	237	339	228	323
4	Jobs cancelled	40	53	37	58	10	4
5	Jobs booked	276	216	209	254	228	298
6	Overdue jobs completed at later date	8	11	2	27	19	40
7	Booked time Man-hours	244	292	243	313	228	297
8	Total time Man-hours	350	393	351	475	360	512
9	Overdue jobs completed this month	6	11	11	0	29	19
10	Overdue jobs (time) Man-hours	6	13	4	35	33	48
11	Reactive maintenance activities	681	376	515	125	534	535
12	Line stop frequency (i.e, B/down)	22	24	58	11	50	29
13	Line stop hours	3	3	6	1	4	3
14	Line stop hours worked	8	6	11	2	6	4
15	Non-line stop frequency	659	352	457	114	484	324
16	Non-line stop hours worked	596	442	242	61	368	217
17	.. ETC ..						

Figure 5.5 Example of categorised maintenance data collected from company

Stage Three: Input the appropriate values from Figure 5.5 into the performance measure spreadsheet

	A	B	C	D	E	F	G
1	Maintenance performance measures: Monthly Input						
2	Information required					Value	
3	MONTH					Enter month date here	
4	Total man-hours worked						
5	Scheduled hours worked						
6	Total overtime worked for period						
7	Predictive and PM inspections completed						
8	Total man-hours of Predictive and PM						
9	Number of jobs completed in period						
10	Number of Jobs overdue in period						
11	Number of jobs in-hand at present						
12	Work orders, Planned and scheduled						
13	Work orders executed						
14	Total cost of scheduled service						
15	... Metrics continued...						

Figure 5.6 Performance measure data input

Stage Four: Output of monthly performance measures

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P		
1	Maintenance performance measures: Monthly Output																	
2	Indices		Value		Indices		Value		Indices		Value							
5	Manpower Efficiency		0.9		Manpower				Maintenance Administration									
7	Overtime		0.0															
9	Utilisation		0.9															
11	Predictive and PM		0.1															
12	M'tance coverage		0.1		Work Order													
14	Overdue tasks		0.02															
16	Work orders, Planned		0.3															
17	and scheduled																	
19	Work orders turnover		0.0		Service Operation													
21	Degree of scheduling		0.01															
23	Breakdown repair hrs		0.01															
25	M'tance hrs applied		12.2															
27	Breakdown frequency		1.0		Plant Condition													
29	Equipment downtime		1.0															
30	caused by breakdown																	
32	Evaluation of PM and		0.8															
33	Predictive M'tance				Plant Performance													
35	Equipment availability		0.99															
37	Length of running		12.5															
39	Emergency man-hours		0.001															
41	Unscheduled tasks		0.1		Economy													
43	Cost of M'tance hours																	
45	PM costs as percent																	
46	of breakdown cost																	
48	Inventory turnover rate				Service Cost													
50	Breakdown severity																	
52	Scheduled service cost																	
54	M'tance costs per unit																	
55	of production																	
56	Month				Overall Index													
58																		

Figure 5.7 Example performance measure output

The structure of the spreadsheet application allows historical comparisons to be made regarding the overall measure and subsequent index ratios. Furthermore, should the need require individual numerators or denominators from the index, ratios can be charted to observe general trends.

5.8 Chapter summary

An overall measure of maintenance performance has been developed to include a number of indicators that signify change through maintenance activity. Some of these indicators seek descriptive information recorded by active maintenance organisations that may help to describe what the impact of using certain lean techniques has upon

their effectiveness. The indicators themselves are not specific 'lean indicators', but are index ratios directly related to maintenance practice. As companies may develop their own ratios under particular circumstances and specific demands, the wide range of indices presented here are by no means exhaustive. Nonetheless, the significance of the indicators compliment each other to the extent that they provide a means to identify (among the host of variables), a great deal of information concerning the maintenance function.

Interestingly, many of the indicator ratios relate to the analogous maintenance wastes presented in Figure 4.2, chapter four. In fact, most of the wastes identified can be, if wasteful, highlighted through the index ratios. Consequently, the index ratio indicators and their various permutations can also be used to monitor progress of change. However, this is only possible if the organisation under investigation measures or records its various activities.

Chapter Six

Industrial investigation through case study research

6.1 Introduction

This chapter investigates, by using industrial case study research, the contribution of lean thinking to the maintenance of manufacturing systems. The aim of the case study research is to assess lean concept use by maintenance practitioners both qualitatively and quantitatively. As such, the use of maintenance performance measures within practical situations is to provide additional quantitative support of lean concept use where possible. Figure 6.1 provides a schematic representation of this chapter:

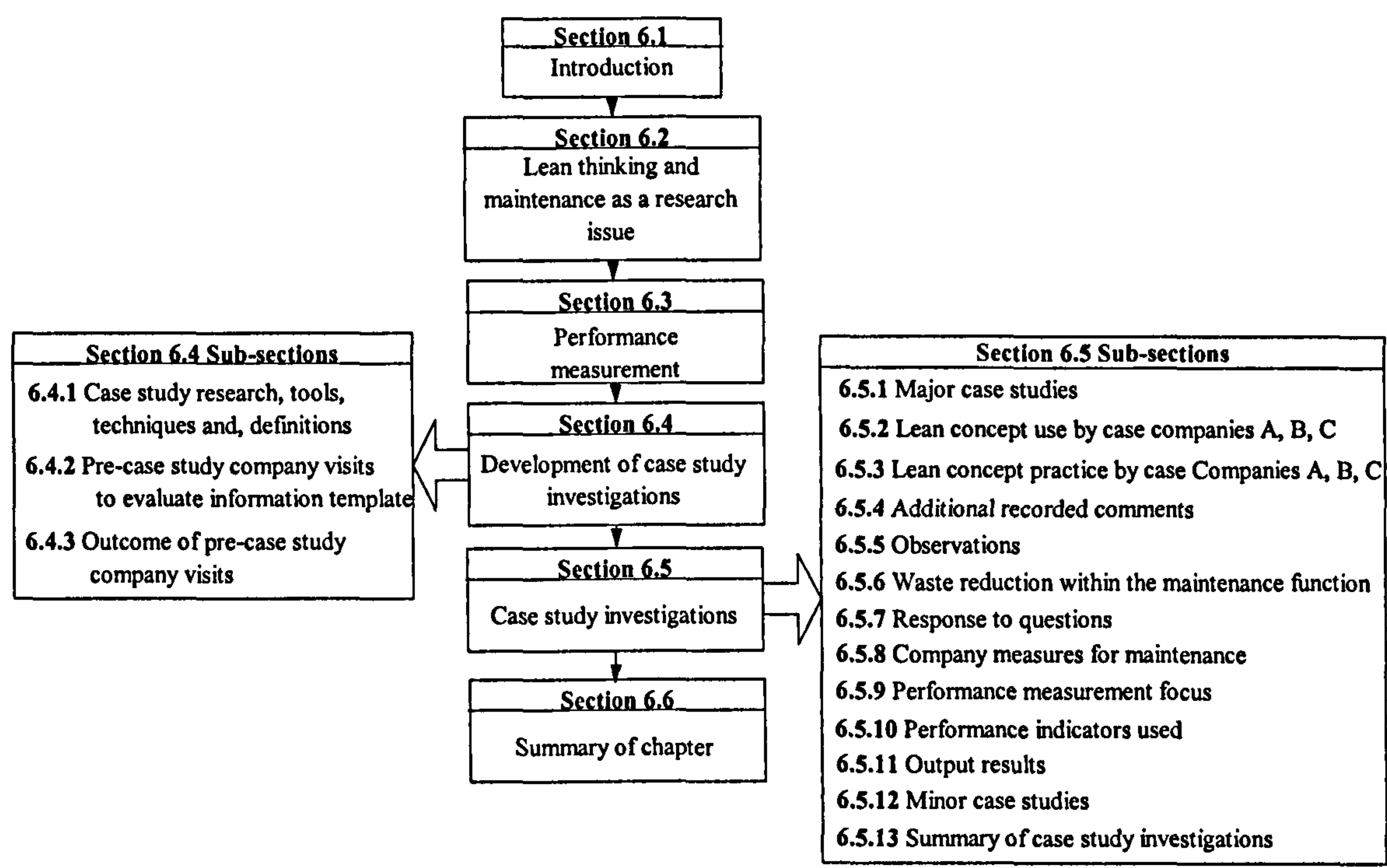


Figure 6.1 Layout of chapter six

6.2 Chapter definition

The following sections convey the industrial case study investigations undertaken by this researcher within the maintenance departments of U.K based manufacturing companies. The investigations are used to answer the research question posed following a review of literature: “How does lean thinking improve the effectiveness of the maintenance function?” The following sections introduce and discuss the following:

- 1 Lean thinking and maintenance as a research issue, and specifically the research problem
- 2 Development of case study investigation including development of tools
- 3 The case study investigations and findings

6.3 Lean thinking and maintenance as a research issue

✓Survey research showed that lean techniques other than TPM are used by maintenance, but this investigation could not identify generic lean practice implementation or a comprehensive list of lean activities used by maintenance (Davies and Greenough, 2001)./Further research identified lean and maintenance as contributors to the effectiveness of an organisation. However, this research could not show the extent of use, or if benefits could be gained from the integration of lean thinking and maintenance. The outcome of this particular research posed the question:

“How does lean thinking improve the effectiveness of the maintenance function?”

To answer the above research question, the following hypothesis was developed to be tested by case study research within active maintenance organisations:

“Lean thinking improves the effectiveness of the maintenance function”.

6.4 Development of case study investigation

The case study approach used by this researcher is based on Yin’s (1994) recommended components of multiple case studies research design, which consists of three distinct areas:

- 1 Define and design (the case study)
- 2 Prepare, collect and analyse
- 3 Analyse and conclude.

6.4.1 Case study research, tools, techniques and, definitions

A method to investigate the research question has been developed. To get to the hypothesis and answer it however requires the selection of appropriate investigation tools, techniques, and definitions. These tools and techniques need to be practical within the reason and scope of the research. Figure 3.4 in chapter three provides a perspective of the case study approach of the researcher. Table 6.1 summarises the various tools, techniques and definitions developed and used by this researcher as part of the ‘define and design’ area of this case study research. In particular, the components used to define the ‘case selection’, or rather participant scope, and ‘design data collection protocol’ for this research, meaning the tools and techniques used to describe, understand and answer the research question

Tools / techniques / definitions	Purpose of use
Definition of maintenance	Standardises the research scope and provides case selection flexibility
Definition of manufacturing systems	Standardises the research scope and provides case selection flexibility
Definition of lean production, lean thinking, lean enterprise	Standardises the research scope and provides case selection flexibility
Research question	Outlines the research and research problem
Hypothesis	From question to statement, used as basis for investigation
Propositions	Containment of the case study research
Maintenance wastes	Waste identification, industry comparisons
Lean reference framework	Identification reference of lean concept use
Maintenance performance indicators	Measure of maintenance performance to identify maintenance effectiveness through activity
Data management methodology	Improve data collection and reliability of analysis
Investigation template	Case visit interview questions, checklists, observations, comprising the above tools / techniques / definitions etc.

Table 6.1, Tools / techniques / definitions and their purpose for this case study research

The investigation template presented in Table 6.1 is used as a guide for this researcher during case visits, and is governed by the propositions of this case study research. The use of propositions helps to ensure that the right amount of information is sought (not too excessive, not too little) without restricting the validity of the research, in particular,

when seeking multiple sources of information that converge. To check the suitability of the investigation template, pre-case study company visits were conducted (discussed below).

6.4.2 Pre-case study company visits to evaluate information template

The researcher undertook evaluation of the information template during single day visits to the maintenance function of six different companies. All companies were aware of the researcher’s motive for the visits, based on introduction by third parties or introduction by telephone or letter. Two companies were approached on the premise of introducing the developed performance measures. The remaining companies were approached with requests to observe their maintenance function in action. Table 6.2 outlines the type of company visited, purpose of visit, and general comments on their manufacturing policy, including the maintenance issue:

Co.	Type of manufacturer	Visit purpose	Manufacturing policy
A	Machine tooling	Observe	TQM, non-lean concept use
B	Car engine	Observe	JIT, TQM, TPM, lean concepts used by maintenance
C	Car assembly	Maintenance performance measures	TQM, JIT, TPM, extensive lean concept use company wide
D	Drive motor	Observe	TQM, JIT, very low-level TPM, extensive use of lean concepts in manufacture process
E	Vehicle fuel systems	Maintenance performance measures	JIT, TQM, TPM, lean concepts used by maintenance
F	CD manufacture and assembly	Observe	JIT, TQM, few lean concepts used in manufacture process
Note: All companies visited conformed to ISO standards			

Table 6.2 Information template evaluation, manufacturer type, visit purpose, manufacturing policy

6.4.3 Outcome of pre-case study company visits

The research propositions, maintenance waste examples, lean reference framework and maintenance performance measures were divulged to all companies visited. All of the lean concepts used by participants were within the scope of the lean reference framework developed by this researcher. All participants understood Ohno's (1988) seven wastes examples and how they may relate to their own maintenance function. Companies C and D understood all fourteen wastes (e.g., Ohno, 1988; Bicheno, 2001) and how they would relate to their maintenance function. The maintenance performance measures were well received. All six companies (despite company A not using lean techniques) understood the content and style of questions put to them.

Participants use and knowledge of lean concepts varied greatly, which provided the researcher with a practical insight to the use of lean concepts. The richest source of lean experience and knowledge was provided by companies C and D. Company C provided useful information concerning their management and trade force approach to their maintenance activities within a lean company, and company D provided examples of their lean philosophy practice within their manufacturing structure. Companies E and F also provided useful information as both companies expressed frustration concerning the implementation of TPM and other lean techniques. They felt that implementation problems were a direct result of their company's JIT employment policy, i.e., commitment was less forthcoming from a seasonal or ever-changing workforce than permanent staff.

Overall, the pre-case study company visits highlighted the suitability of the maintenance performance measures to be used for investigation, the type of questions posed, and the lean framework used. However, they also taught this researcher not to provide too much information regarding the variant possibilities of the overall measure of maintenance performance. Therefore, only a brief outline of the measures would be given in future case study investigations. In retrospect additions were included within the template that reflected some of the observations made by this researcher during the visits. Such examples were the visibly noticeable approaches used by some companies to the practical use of storyboards, TPM and 5S, etc.

The case studies undertaken, using the tools and techniques developed and tested through pre-case study investigations, are presented and discussed below.

6.5 Case study investigations

Three major and two minor case study investigations were undertaken by the researcher to investigate the research question through use of a hypothesis. Although the outcome of all five case investigations are presented and discussed here, Appendix A and B are used to highlight the full research undertaken within the maintenance function of two car manufacturers. Case selection was through a process of elimination to find those companies within reason, likely to provide the richest source of reliable information and data. The process, from seeking participants to those fully investigated is given here.

For this research, a mixture of U.K situated companies were approached by mail shot requesting help with ongoing research. Of the one hundred companies approached, some were known to use at least two of the three characteristic elements of lean production, TQM, JIT and / or TPM. The remaining companies were found, with very little pre-knowledge of their background, by using online business directories. Figure 6.3 highlights the response rate from twenty-six of the maintenance and production managers approached, the number of visits generated from the replies and limitations experienced after follow up enquiries. Additional replies from various companies and consultants were not considered, as these were only requests for information. Appendix C provides an example of the request letter and research outline sent to companies.

Product or service	Replies	Visits	Limitations
Car manufacturer	5	5	None, free access
Automotive supplier	5	3	Two backed out after follow-up queries
Snack foods	1	1	None, free access
Aircraft	1	0	Too far to travel
Aerospace supplier	2	1	Union restrictions for one company
Building systems	1	0	Maintenance department too small
Precision engineering	1	0	Maintenance department too small
Process	4	1	1x Oil, 2x Chemical too far to travel
Sellotape	1	0	Maintenance department too small
Contract maintenance	2	0	Both lost their site contracts after receiving info'
Air compressor	2	0	Maintenance department too small
Pharmaceutical	1	0	Relocation of manager
TOTAL	26	11	

Table 6.3 Mail shot research request replies

After satisfactory follow-up queries, each company visited from Table 6.3 was approached with the intention of undertaking a full case study investigation. However, six of the eleven companies could not be researched beyond the preliminary interview and / or observation stage of the research. For reasons of confidentiality, two companies could not be investigated beyond gathering basic information. Two companies were seeking commercial advice for implementing lean concepts within their maintenance departments beyond the scope of this research. One company, as a result of three senior management changes within two years was seeking an alternative to their current manufacturing approach, also beyond the scope of this research. The maintenance policy of the snack food manufacturer was strictly controlled by their client companies manufacturing standards and policies. So, although using some lean concepts and keen to participate in the research, it was felt that a balanced investigation of their maintenance function could not be undertaken. Table 6.4 provides a list of the major and minor case study companies investigated for this research:

Case	Company type	No. employees (Approximate)	No. site Maintenance (Approximate)	Case evaluation
A	Car manufacturer	2500+	100	Major
B	Car manufacturer	9000+	130 (2/3 sites)	Major
C	Car manufacturer	2000+	98	Major
D	Car manufacturer	2900+	75	Minor
E	Car manufacturer	292+	119	Minor
Note: Company E, only the body stamping site was investigated				

Table 6.4 List of case study companies

6.5.1 Major case studies

The three major case studies discussed here were conducted within an 18-month period, from approximately November 2000 to April 2002. Of the case studies conducted, companies A and B are still active concerns, and were investigated as such by this researcher. For company C, this researcher undertook retrospective investigations as the company was in the last four months of its operations before closure. As such, some of the queries made by this researcher could not be applied to company C, i.e., seeking their opinion on the future of lean practice within their maintenance function. Table 6.5 presents an outline of the case study participants, the type of data and information collected, and the period of information made available to this researcher:

Case	Information and data	Participants	Period of investigation
A	<u>Interviews:</u> Semi-structured <u>Documented evidence:</u> Photographs / documentation / recorded *MMIS data <u>Observations:</u> Visual site / plant checks	<u>Maintenance:</u> 2 x Managers 1 x Supervisor 1 x Technician	1997 – 2001 This period includes extracted MMIS data
B	<u>Interviews:</u> Semi-structured <u>Documented evidence:</u> Photographs / Reports / documentation / manuals / recorded MMIS data / lean improvement project examples <u>Observations:</u> Visual site / plant checks	<u>Maintenance:</u> Department Head 2 x Managers 3 x Technician	1998 – 2002 This period includes extracted MMIS data
C	<u>Interviews:</u> Semi-structured <u>Documented evidence:</u> Documentation / manual / recorded MMIS data <u>Observations:</u> Visual site / plant checks	<u>Production:</u> Ops manager 1x Prod. supervisor <u>Maintenance:</u> 1 x manager 1 x Senior engineer	2000 – 2001 This period includes extracted MMIS data
*Note: MMIS refers to maintenance management information system			

Table 6.5 Major case study information sources and data collection

6.5.2 Lean concept use by case companies A, B, C

Semi-structured interviews and visual checks were conducted within the case study companies to understand the level of use, and application of lean thinking practices from a maintenance perspective. The participants questioned were given a brief description of the lean practices possible within a company, and maintenance in particular, including an explanation of terminology and clarification of the issues. Table 6.6 summarises the lean activities used by the maintenance functions under investigation and approximate year of implementation:

Lean Concepts	Company A	Company B	Company C
Standards	1996	1998	X
Pokayoke	1996	1999	1998
Root cause problem solving	1996	1999	1996
Process activity mapping	1996	2000	X
TPM / FTPM	1996	1998	1998
Inventory Management	1999	1996	1998
Storyboarding	1999	2000	1998
Visual management	1999	1998	1998
Self audits	1999	X	1998
5S (Cando)	2000	1996	1998
Continuous improvement	2000	1997	1998
Kaizen activities	X	1997	X
Overall equipment effectiveness	X	1997	X
Supplier associations	X	1996	X
Mapping (human / resource)	X	2001	X

Table 6.6 Lean concepts used by case companies A, B, C

6.5.3 Lean concept practice by case Companies A, B, C

Standards: Maintenance within companies A and B both align themselves with continuous improvement (CI) approaches and ISO 9000 and ISO14001 standards use. Maintenance personnel are encouraged to seek ways to standardise their work for improvement. Skill matrix charts are also used to identify current capability and future training needs.

Pokayoke: The approach to mistake proofing by the case companies is identical. All use combined production and maintenance teams to undertake early equipment management (EEM) and new equipment procurement (NEPT) procedures. These teams are biased toward automated mistake prevention for production. Company B also involves technical services and vendors / suppliers for large-scale projects.

Root cause problem solving: This methodology is considered a standard procedure by companies A, B, and C. Similar methods were used prior to lean-implementation and are considered a standard procedure. Overall, root cause problem solving and Pokayoke

(mistake proofing) for all the companies are similarly practised using a parallel method of the 5 whys approach.

Process activity mapping: Both companies A and B have used process activity mapping but only really for major overhauls, shutdown maintenance, and production projects. For company A, process activity mapping for shutdown maintenance is the responsibility of maintenance planning. For company B, technical services provide co-ordination

TPM / FTPM: For company A, the introduction of TPM coincided with the phasing out of trade demarcation within maintenance, and the introduction of team based multi trade functions. For company B, TPM has been reintroduced more forcefully within the company since 1998-1999 as previous attempts lacked long term support. For company C, the introduction of TPM was through operator rather than management initiatives. Although TPM for each company has evolved from awareness training through local responsibility, to low level escalation practices, some PM activities are still carried out by maintenance during non-production hours.

Inventory management: The interpretation by maintenance of lean inventory management for company A extends to the use of a rotational first in first out (FIFO) system for bearings and seal replacement, etc. Similarly for company's B and C, FIFO is also used. Company B has also recently formed vendor and supplier associations to improve spare part replacement reliability, and collaboration during improvement and new project developments. In addition to FIFO, company C also have line side spare part trays and tooling shadow boards in some areas, with their maintenance function making use of supplier relationships for their inventory needs from time to time.

Story boarding: All three companies use maintenance storyboards to highlight project updates, quality improvements, control charts, etc., on a weekly basis. Company A also e-mails section managers and supervisors with weekly updates. Storyboard examples from company's A and B are highlighted in Appendix A and B. For company C the most visible benefit of story boarding for maintenance are during periods of project changes and shutdown maintenance.

Visual management: For all three companies visual management is considered a standard. All use 'Andon' board lights and standard operations sheets. Company's A and B also use an auto fault register. Additional visual management tools such as improved information retrieval techniques (e.g., bar-coding for Company B), clarity of task ownership (companies A, B and C) and ongoing standardisation are pursued by the

companies. However, the use of GEMBA (shopfloor innovation) has yet to be a commonly used philosophy within maintenance, particularly within Companies A and C.

Self-audits: For company A, initial attempts at self-assessment questionnaires within the maintenance department were very poorly received and subsequently phased out. However, management as part of a wider corporate assessment do conduct performance audits with individuals. For company C, individuals undertake low-level audits regarding their tasks; management also conducts performance audits.

5S (CANDO): All three companies practice 5S. Company A introduced 5S plant wide to coincide with a decentralised maintenance policy, i.e.; the maintenance technicians went trackside. The emphasis of 5S by company B, based on very practical needs, is well understood by everybody and is part of the company culture. For example, floorspace is an issue, so orderliness and cleanness are necessary. In company C, although maintenance practices 5S, lineside production operators lead the main emphasis of the 5S approach.

Continuous improvement (CI): CI is the ongoing summation of the previous lean activities introduced by each of the companies A, B and C. For company A, the concept and encouragement of CI concerning maintenance is management led and requires more time for it to fully succeed. Acceptance of CI is inhibited by the retention of traditional methods of reporting (i.e., escalation, of technician to supervisor, to manager, etc.), which management are trying to presently overcome. For Company B, maintenance personnel although led by technical services, practise the concept and encouragement of CI. For company C, the concept and encouragement of CI concerning maintenance although management led, does not require constant monitoring or enforcement.

Kaizen activities: The maintenance function and technical services of company B use Kaizen workshop activities for monthly improvement meetings to eliminate wastes in maintenance (e.g., the experimental reduction of PM tasks and activities) and implement improvements.

Overall equipment effectiveness (OEE): The use of OEE by company B has been patchy due to poor control, in part resulting from management changes, staff shortages, manufacturing system and ownership changes, etc.

Supplier associations: Company B initiated supplier associations in 1996 to improve spare parts delivery. Early initiatives proved successful but soon tailed off as a result of

vendor “disinterest” (*Manager, technician*) and “support” (*Manager, technician*). This was redressed in 2000, whereby vendors and contractors were “obliged” (*Manager*) to improve delivery co-operation, design co-operation and training, or risk losing business.

Mapping: maintenance and technical services of company B use general mapping, but only when production requires planned resource logistics as a combined initiative.

6.5.4 Additional recorded comments

In addition to answers given during questioning, some notable comments were recorded:

“Overall equipment effectiveness (OEE) is not used by the maintenance department, but has on occasion been used by production. Maintenance would consider using OEE if a new assembly line were introduced, but prefer measuring mean time to failure (MTTF) in the production environment...” (*Manager, Company A*).

“The introduction of work practices (*i.e., TPM etc.*) has not unduly affected maintenance in terms of staff turnover, which remains less than 2%. Overall, the practices that have been accepted by the workforce are viewed as additional tools to help them with their jobs” (*Manager, Company A*).

“In fairness, some of the approaches we now use, described as lean practices have been used in some form or another for many years. They are a combination of practices previously used that have been combined to form a more common sense approach to the problems we previously had”. (*Managers, Company A*).

“Over recent years the company has experienced unprecedented demand for its product, gone through change of ownership, coped with skills shortages especially in maintenance, overcome production quality issues and improved manufacturing capacity with decreasing workspace availability. In turn, this has forced the maintenance function to evaluate its capability and contribution to the business in terms of accountability, quality of service and flexibility. Hence, the re-emphasis of previous lean practices and the introduction of newer lean techniques, among others. The formation of a technical services department, as a centre for innovation and driver for waste reduction and improvement, has allowed an understaffed maintenance function to focus more on its task requirements without losing touch with change. By taking this approach, maintenance feel that it is less likely that any beneficial changes introduced would fall to the wayside as a result of other issues. Overall, the introduction and use of lean

techniques by maintenance have been generally accepted as useful tools to use. However, there is still a long way to go in terms of lean innovation and practice.”
(*Head of department for technical services and maintenance, Company B*).

“During 1995 the company tried introducing lean practices e.g., TPM, 5S, continuous improvement etc., which lasted about six months. The failure of lean thinking practices to take off was through lack of workforce consultation; it was too management oriented; and not clearly defined in terms of its objectives and benefits. In 1998 the reintroduction and use of lean practices came from a simple mood change brought on by a new manager and increased output demands. Put simply, car sales increased, sections of the workforce were getting tired of the blame culture when output fell. Other sections were also getting tired of constant factory visit cleans. It was as simple as that; change came about, as it seemed the right thing to do at the right time. However, this is not to say that we are not learning from our mistakes or forgetting our achievements” (*Production supervisor, Company C*).

6.5.5 Observations

Visual checks by this researcher, both accompanied and unaccompanied, were conducted at all sites over a number of visits. Most documentation provided to this researcher was not for public domain. However, photographic evidence can be seen in Appendices A and B, along with a more thorough discussion of this researcher’s visits.

Company A: This company has a dedicated TPM administration centre on the shop floor co-ordinating the manufacturing systems operations. The use of 5S was evident throughout the plant and maintenance areas, although it did fall short of a clean desk policy within office areas. Issues concerning TPM activities, responsibilities, etc., were shown on storyboards throughout but not as visual machine-side record sets. Storyboards were positioned throughout the factory and satellite maintenance areas, providing up to date information. As part of the visual checking process a manager also provided documentation concerning skills matrix charts, NEPT and EEM practices, and vendor feedback documentation as used by maintenance.

Company B: The use of 5S was evident throughout the plant and maintenance, as were production line-side spare part trays. Issues concerning lean procedures, activities, progress, responsibilities, etc., were shown on storyboards throughout the factory, satellite maintenance areas, and technical services. Tooling shadow boards or visual machine-side record sets concerning TPM activities, responsibilities, etc., were not noticeable.

During the observation period, a manager provided documented examples of skills matrixes used by maintenance, NEPT (new equipment purchasing teams) and EEM (early equipment management) and vendor feedback documentation. Current vendor / supplier association agreements with maintenance and technical services, energy management initiatives, project plans, improvement proposals, an overall maintenance business plan for 2001, and maintenance assessments were also provided. Additionally, maintenance and technical services also provided information to highlight their use of lean thinking in an improvement project. Appendix B discusses this in detail.

Company C: As company C was in the process of closing down during this researcher's visits, many visual examples of lean use had already been moved or were about to be moved. However, the use of 5S was evident throughout the plant, as were production line-side spare part trays and shadow boards. Issues concerning lean procedures, activities, progress, responsibilities, etc., were shown on storyboards but had not been updated for a number of weeks. The outline of previous tooling shadow boards and documentation stations were visible around workstations. An example of a TPM work manual and combined maintenance and production process documentation was given to the researcher.

6.5.6 Waste reduction within the maintenance function

An example of lean production wastes and analogous wastes within maintenance was explained to interviewees, who were then asked to identify similar wastes within their maintenance department and explain how they are tackled. Table 6.7 highlights the maintenance related wastes identified by the interviewees, and explanations of how they are tackled. Although all of the interviewees understood the important issue of waste elimination, overall it was the managers who had a better understanding of lean wastes present within maintenance.

	Company A			Company B			Company C	
	Maintenance wastes	How maintenance wastes are tackled	Maintenance wastes	Maintenance wastes	How maintenance wastes are tackled	Maintenance wastes	Maintenance wastes	How maintenance wastes are tackled
Production wastes								
Overproduction	Excessive PM activities	Planned / scheduled PM activities	Excessive PM activities	Planned / scheduled PM activities		Not applicable	Not applicable	
Waiting	Waiting for resources	Satellite workshops/stores, lineside trays	Waiting for resources	Satellite workshops/stores, lineside trays		Response time to breakdown	Decentralised lineside maintenance	
Transporting	Centralised maintenance	Decentralised lineside maintenance	Centralised maintenance	Decentralised lineside maintenance		Distance between Job & workshop	Spare part and tooling shadow boards	
Processing	Excessive TPM activities	Escalation capping (capability guidelines)	Excessive TPM activities	Escalation capping (capability guidelines)		Not applicable	Not applicable	
Inventory	Excessive stock	First in First out spare parts	Excessive stock	First in First out spare parts		Excessive stock	Computerised stock control	
Motions	Could not define	Could not define	Could not define	Could not define		Slow response times	Decentralised lineside maintenance	
Defects	Poor maintenance	Skills Matrix, EEM NEPT teams	Poor maintenance	Skills Matrix, EEM NEPT teams		Poor maintenance	Repaired part retest prior to reuse	
Human potential	Lack of training	Skills Matrix, taught courses	Lack of training	Skills Matrix, taught courses		Lack of training	‘Horses for courses’ best skill + TPM	
Inappropriate systems	Poor information	Automated fault systems, training	Poor information	Automated fault systems, training		Poor information	Monitored & improved with user agreements	
Energy Mgmt	Energy management	ISO 14001	Energy management	ISO 14001		Energy management	ISO 14001 site issue	
Materials	Poor re-design	NEPT / EEM teams	Poor re-design	NEPT / EEM teams		Poor re-design	5 Why’s, Pokayoke	
Service / office	Could not define	Could not define	Office wastes	Recycling		Waste paper	Recycle policy; ‘switch those lights off’	
Customer time	Poor procedures	Standards / storyboards	Poor procedures	Standards / storyboards / training		Not applicable	Not applicable	
Customer defection	Poor maintenance	Skills matrix, Training	Poor maintenance	Skills matrix, Training internal / external		Not applicable	Not applicable	

Table 6.7 Production wastes, maintenance wastes, and tackling the maintenance wastes

6.5.7 Response to questions

All of the interviewees were asked the same questions concerning their opinion of lean thinking within maintenance. Table 6.8 shows the response to the question: “What have been the benefits of introducing various lean concepts to the maintenance function?”

Company A	Maintenance manager 1	Increased workforce responsibility; Less skill demarcation; Increased throughput; Less firefight maintenance; Standardised procedures / activities; Greater product awareness; Work team unity
	Maintenance manager 2	Reduced downtime; Fewer unscheduled tasks; Waste reduction; Decentralised maintenance; Improved team and production communication; Faster response times; Automated fault system
	Maintenance Supervisor	Clearer task definition; Less firefighting; Better communication; Better facilities; Quicker breakdown response; Easier access to spare parts; Access to further learning
	Maintenance technician	Less skill demarcation; Greater team responsibility; Better communication; Better access to information; Less firefight maintenance; Less unscheduled tasks; Less time spent machine minding
Company B	Head of Dept. maintenance	Increased workforce responsibility-ownership; Better skill integration; Increased throughput; A more robust maintenance function; Standardising of procedures / activities
	Maintenance manager 1	Clearer task definition; Shared responsibility; Waste reduction; Improved maintenance quality and service; Improved management, team and production communication
	Maintenance manager 2	Problem solving techniques; Greater task flexibility; Task ingenuity-innovation; Better facilities; Less firefighting
	Maintenance tech. (x3)	Less firefighting; Less skill demarcation; Better communication; Quicker breakdown response; Access to training -information
Company C	Ops manager	Better production / maintenance integration; Accountability of the actions of production; Less unscheduled maintenance
	Production supervisor	Better self control of workstations; De-mystification of maintenance; Improved morale; Better work environment; Skills building
	Maintenance manager	Closer ties with production on improvement projects; Reduced blame culture; Less demand on manpower; Overall improved quality
	Senior engineer	Less blame; More flexibility; Less firefighting; More training courses; Better communication with vendors, production and management

Table 6.8 Response to question: “What have been the benefits of introducing various lean concepts to the maintenance function?”

Table 6.9 shows the responses to the question: “Has there been a downside to the lean concepts used within the maintenance function?” Appendices A and B highlight fuller responses from companies A and B.

Company A	Maintenance manager 1	“Lack of understanding and unwillingness of some to accept change. Translation of production led lean techniques to suit maintenance. Initial reluctance to share maintenance knowledge with production”
	Maintenance manager 2	There have been various activities suggested or implemented that have not really been successful in terms of acceptance or workability”
	Maintenance supervisor	“I am kept informed of the successes through storyboards and e-mail updates but not so much the non-starters”
	Maintenance technician	“Not really, a few teething problems here and there and a couple of non-starters, but on the whole ok”
Company B	Head of Dept. maintenance	“Unwillingness of some to share their maintenance knowledge with production, and accept lean practices resulted in a high staff turnover. Translation of essentially business and production led lean techniques to suit maintenance function.
	Maintenance manager 1	“Various practices implemented in the beginning, were not really successful in terms of acceptance, workability or just died out”
	Maintenance manager 2	“If you take away the earlier lack of success, then overall, the use of lean within maintenance has been no bad thing, despite the shortage of required on roll manpower”
	Maintenance tech. (x3)	“Previous lean initiative roll-outs asked too much, too soon, in too wide an area, making it difficult for some to cope with the change”
Company C	Ops manager	“A lack of communication in the early stages, but nothing serious”
	Production supervisor	“A major obstacle was trying to convince management and maintenance that a change was needed, and having to learn from mistakes”
	Maintenance manager	“It took a while to see the benefits, but otherwise no real problems”
	Senior engineer	“As the initiative was led from the shopfloor there was a lot of cynicism which may have slowed down progress in the beginning”

Table 6.9 Responses to question: “Has there been a downside to the lean concepts used within the maintenance function?”

Interviewees within companies A and B, (not C unfortunately, as the company was closing down and so were unable to contribute to this question) were asked their opinion on the continued use of lean concepts within their maintenance department and how they viewed the future growth. Table 6.10 shows the responses from this question:

Company A	Maintenance manager 1	“Consolidate the more recently accepted lean practices, introduce greater decision making autonomy, i.e., change / idea start-ups etc. Integrate maintenance more with manufacturing production, i.e., as facilitators of continuing first line and EEM maintenance solutions”
	Maintenance manager 2	“Introduction of line side shadow boards, better information systems, and improved skills acquisition for technicians”
	Maintenance supervisor	“I would like to see more organisation transparency”
	Maintenance technician	“See what happens”
Company B	Head of Dept. maintenance	“Build and expand lean practices already in place, and introduce greater decision making autonomy, i.e., change / idea start-ups etc throughout. Get production to buy into maintenance, starting with the planned revised approach to OEE practice. Promote greater business awareness and contribution within maintenance at all levels. Develop greater worker ownership of facilities, including all none critical maintenance and improvement strategies, enabled by the facilitation of the combined maintenance and technical service function.”
	Maintenance manager 1	“Build on the earlier successes of EEM and NEPT activities. Develop greater involvement at all levels in all areas, concerning new equipment design or redesign for improved production facilities”
	Maintenance manager 2	“Develop more effective use of technology and resources, that not only assist the maintenance function but aspects of production as well. Work on greater interaction between production and maintenance, to reduce the various types of dependency one has upon the other”
	Maintenance tech. (x3)	“Greater personal development and responsibility. Access to further training, in particular business awareness and management. Be seen more as facilitators of improvement and efficiency change throughout production. As processes improve and automation becomes more common, our professional skills will focus more on high-tech solutions, whereas line-side operators will take ownership of lower level non-critical maintenance and improvements”

Table 6.10 The future of lean practices within maintenance?

6.5.8 Company measures for maintenance

Companies A, B, and C when visited by this researcher did not directly measure the overall performance of their maintenance function. A basic measure for maintenance performance is throughput, i.e., has the volume of cars manufactured increased or

decreased? If the volume has decreased, what are the reasons? For each company therefore, maintenance performance was inferred from operational performance and focused on process improvement and reduction of production downtime.

Companies A and B although operationally independent of each other, are part of the same global organisation. Both changed from using a customised MMIS to record their activities in 2001, to using a unified Intranet based information system installed by their parent organisation. Previously, the use of an MMIS allowed company A to record 'zone-based' maintenance activities. For company B, the use of the MMIS was by site manufacturing areas. Company C retained its use of an MMIS and similar to company A, preferred to measure its maintenance activity zone by zone. Raw data provided, collected and used for companies A and B are provided in Appendices A and B.

6.5.9 Performance measurement focus

For company A, the period of measurement extends from January 1997, shortly after implementing TPM through to June 1999. Thereafter, data becomes less consistent and reliable. For company B, available recorded data was from January 1998 to July 2001. Company C could only provide twelve months worth of data between January 2000 and June 2001.

The focus of MMIS data collection by this researcher centred on the recorded activities of particular zones within companies A and C. Although both companies recorded their activities zone by zone during this period (1997-1999; 2000-2001) it was more practical for this researcher to investigate those zones with the highest level of reporting consistency, and interviewee experience of that area. For company A, this was trackside maintenance, and for company C, the frame assembly area. Both companies' primary production equipment had been in place since 1993 / 1994 and was considered neither too new, nor too old to exhibit early or late life failure modes that may otherwise distort readings. Both zones also had a low staff turnover rate, nominally less than 2% per annum throughout for company A, and slightly higher for company C (approx. 3 –5%).

In company A, a maintenance technician who managed the MMIS for the site assisted this researcher in the collection of raw data for analysis. For company C, during the interview process with the senior engineer, explanations were given for probable causes of activity, disruption, and missing data during the measurement period. For example, budget and schedule cuts in January 2000 meant that overtime was stopped for a while, which affected the amounts of PM and TPM being conducted. During this period, the

redeployment of operators for work on a new model system also meant that fewer people were available for PM and TPM activities. Missing data between August 2000 and Feb 2001 (6 months) were in part attributed to the events leading to, during and post closure notification of the plant. However, it was also explained that either someone had forgotten to inform of the whereabouts of the records prior to leaving, or had simply neglected to record activities during this period.

Company B measured its activities by manufacturing assembly plant rather than zones within each plant. Nonetheless, prior to collecting the data from company B’s MMIS, a maintenance manager and technician were interviewed concerning issues that they felt might affect the accuracy of the data collected. Table 6.11 highlights the issues discussed and what effects they had on the maintenance function during the period of collection (i.e., MMIS data from January 1998 to July 2001). Short periods of disruption (industrial action, new model introduction, etc.) were considered not to be of significant importance by the interviewees. After the data was analysed further, answers were sought from the interviewees to explain periods of disruption not previously discussed. Additional information provided by the interviewees stated that there has been a long-term shortfall of ten maintenance engineers “required on roll” (*Manager*) within the site under investigation.

Major issues affecting maintenance during period of data collection		
Month(s)	Event	Impact on maintenance
11-15	Installation of primary equipment during month 10	Increase in breakdown repair hours, decrease in PM activities
21-24	Increase in accessory lineside equipment alterations for “production ramp-up” in month 28 and model change introduction in month 31	Increase in breakdown repair hours during trial runs and tests
25-27	Continued preparation for ‘production ramp-up’ in month 28 and model change introduction in month 31	High number of unscheduled tasks resulting from trial runs and tests from months 21-24

Table 6.11 Issues affecting company B’s maintenance during measurement period

6.5.10 Performance indicators used

Based on three criteria a spreadsheet application is used to calculate performance in terms of the indicators discussed in chapter five. These three criteria were ease of data

retrieval, cost of retrieval, and ease of understanding the results. The availability and type of data recorded by the maintenance functions of companies A, B, and C determined the selection of usable indicators. Table 6.12 summarises the performance indicators chosen for the investigations, based on the lean techniques used, and availability of data from the MMIS used by the various maintenance functions.

The indicators as presented in Table 6.12, are used to measure the impact of the lean techniques presented in Table 6.6, and the subsequent impact they have upon the maintenance functions investigated. However, excluding concepts that could only be assessed subjectively, and those for which MMIS was not available, only six of the fifteen lean concepts presented in Table 6.6 could be investigated. These are: TPM/FTPM; continuous improvement; OEE; standards; Pokayoke; and root cause problem solving.

Performance indicator	Indicator calculation	Desired outcome
Breakdown repair hours	$\frac{\text{No. hours spent on breakdowns}}{\text{Total direct maintenance hours}}$	Trend decrease
Evaluation of PM and Predictive maintenance	$\frac{\text{Predictive and PM insp. completed}}{\text{Predictive and PM insp. scheduled}}$	Trend increase to unity
Manpower efficiency	$\frac{\text{Hours worked as scheduled}}{\text{Total hours worked}}$	Trend increase to unity
Equipment availability	$\frac{\text{Equipment runtime}}{\text{Equipment runtime} + \text{B/Down time}}$	Trend increase to unity
Maintenance hours applied	$\frac{\text{Total maintenance hours}}{\text{Total production hours same period}}$	Once established ratio should tend to decrease or stabilise
Length of running	$\frac{\text{Tot Prod. output in units or hrs}}{\text{Qty repairs for same period}}$	Value increase
Unscheduled tasks	$\frac{\text{Man-hrs unscheduled jobs}}{\text{Total maintenance hours}}$	Trend decrease

Table 6.12 Maintenance performance indicators used for this investigation

6.5.11 Output results

Based on the available information extracted from the MMIS of companies A, B and C, Table 6.13 highlights the change in the performance indicators resulting from the activity of the various maintenance functions under investigation. Findings for companies A and B are discussed more fully in Appendices A and B. Representations

within Table 6.13 for company B, exclude the periods of disruption already highlighted in Table 6.11 and discussed in detail in Appendix B. The index outputs for company C are presented in Figures 6.2 - 6.4.

Performance indicator	Change through activity		
	Company A	Company B	Company C
Breakdown repair hours	↓	↓	↓
Evaluation of PM and Predictive maintenance	Do not track historical overdue PM schedules	→	No data
Manpower efficiency	No data	→	→
Equipment availability	Do not measure	→	Do not measure
Maintenance hours applied	Total hours inclusive	stable	Hours capped
Length of running	↑	↑	Only repair hours booked
Unscheduled tasks	↓	↓	↓
Notation: ↓ decrease, ↑ increase, → increase toward unity, ← decrease toward unity			

Table 6.13 Performance indicator changes through maintenance activity

The output graphs generated from the available data retrieved from company C are presented here in Figures 6.2 - 6.4. A trendline is used to visually highlight the change in performance over the period of data retrieval.

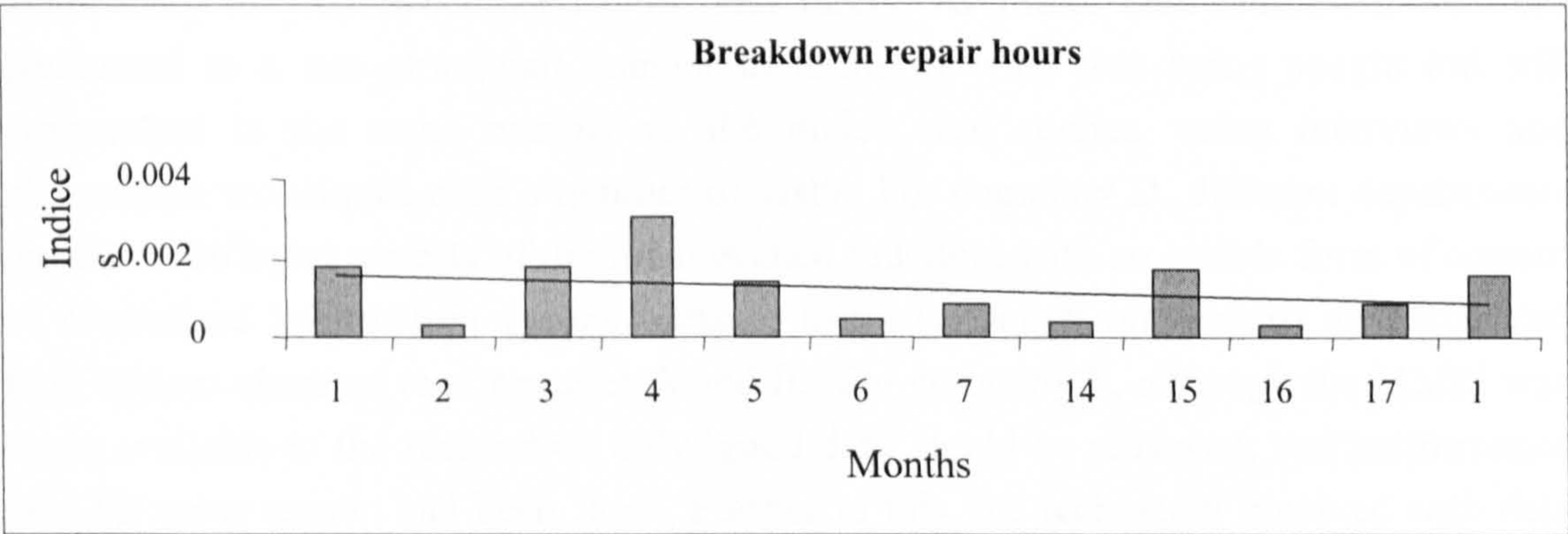


Figure 6.2 Breakdown repair hours indices for company C

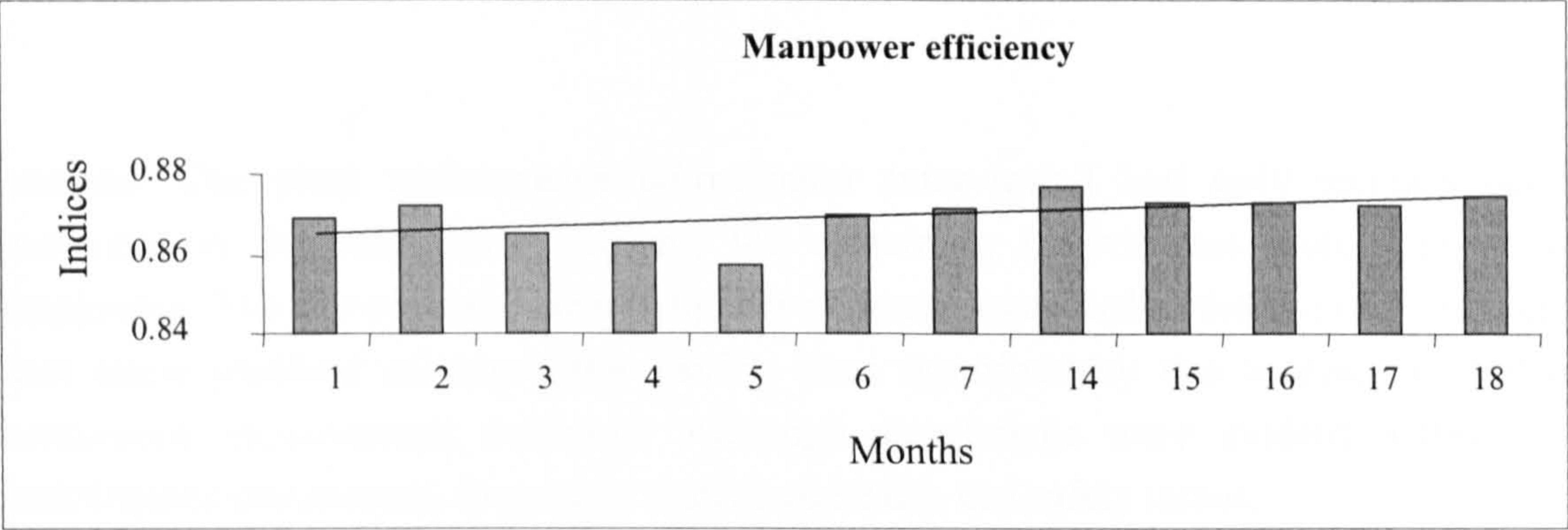


Figure 6.3 Manpower efficiency indices for company C

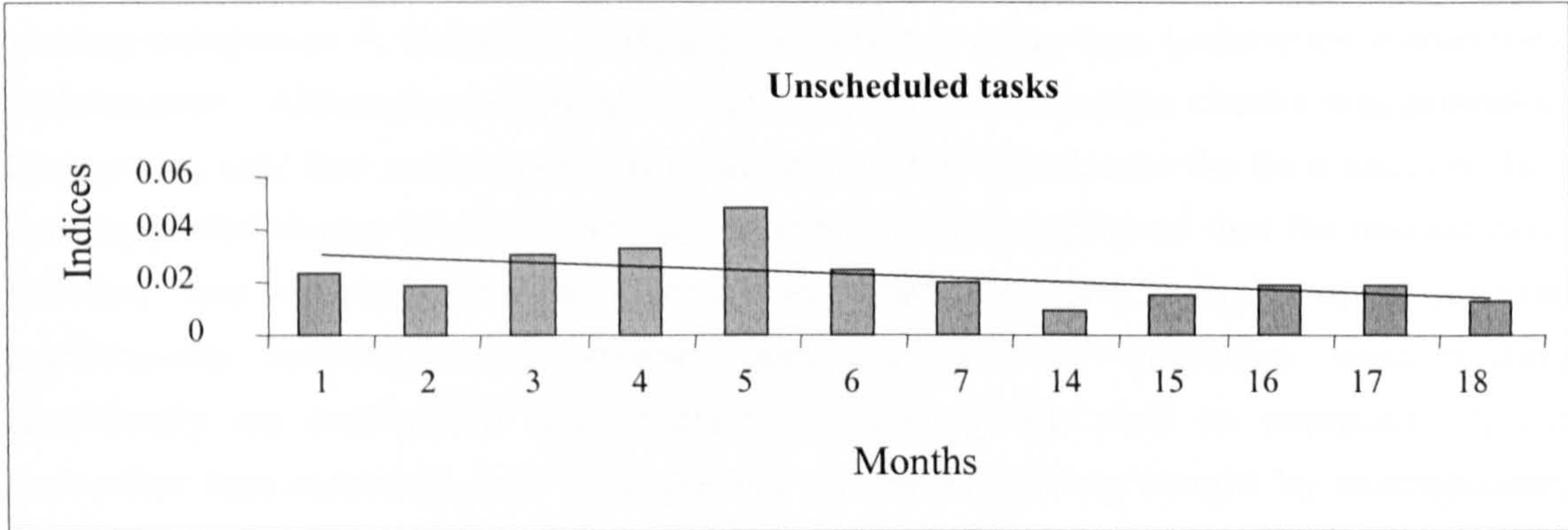


Figure 6.4 Unscheduled tasks indices for company C

6.5.12 Minor case studies

In addition to the major case study investigations, this researcher also took the opportunity to visit two other car manufacturers. As minor case studies, these were conducted in a less structured manner in terms of what was being sought but still approached in the same manner as the major case studies, using interviews and observation techniques over a number of visits. For company D, different departments measured different aspects of the maintenance function, with no visible form of control or centralised information system, despite using (although unmanned) an automated fault system identical to companies A and B. For company E, although the MMIS was made available to the researcher, only ‘good data’ could be retrieved; bad performance data for some reason had been ‘lost’. Further to this, the technician involved with data management was fairly new to the task and could not retrieve data from previous years.

The interview and observation process at company D was carried out in one day, comprising brief interviews with the plant maintenance co-ordinator and maintenance-planning engineer, and lasting about an hour each. A lineside operator and maintenance supervisor were asked questions, but their contribution only extended to very brief

answers. The plant maintenance co-ordinator interviewed had only recently been promoted to the role from 'design'; the remaining interviewees were long term employees. The use of lean concepts by this company extended to the use of Pokayoke, root cause problem solving (after having been described by this researcher) and a continuous improvement initiative. Although storyboards were evident within the maintenance department, these only contained health and safety issues.

The researcher was escorted by the maintenance planning engineer during the site tour of company D. From the researcher's point of view, and the experienced gained from visiting companies A, B and C, company D were not using lean techniques within their maintenance. Although an example of daily operator production checks was provided, an operator said that maintenance still carried out the PM checks for their section. This was supported in part by a maintenance supervisor, who explained that the maintenance function was divided into two parts. One part focussed entirely upon planned maintenance activities, and another part consisted of engineers concentrating specifically on breakdown maintenance. In closing the visit to company D, the researcher was informed that "changes are continually being sought by management, and they are needed. It is just that a lot of dead wood needs clearing out first".

By the time this researcher had conducted the third and last visit in April 2002, company E had recently recruited their fourth senior supervisor to the role of lean improvement co-ordinator. The first co-ordinator was interviewed by this researcher in July / August of 2001, shortly after the company had failed an internal audit of their maintenance function. During each visit, this researcher continued to interview people, make observations and be informed of progress (i.e., the outcome of audits and general changes throughout the department since the last visit). Prior to the last visit, company E had been informed that it had only just passed its last audit assessment, but changes were still needed. The changes recorded between the first and last visit by this researcher are discussed here.

As newcomers to the adoption of lean concepts within maintenance, company E was first introduced to TPM in 1998, all other concepts were introduced in 1999 and 2000: standards, Pokayoke, and root cause problem solving in 1999, 5S and continuous improvement in 2000

During the first visit, it was found that company E was having problems getting initiatives 'off the ground'. Everybody interviewed from supervisors to technicians, felt that too many initiatives were being 'bought online', with too few people to manage them. It was strongly felt that the 'build-up' of initiatives and the 'just do it' philosophy

were drastically slowing down the progress of earlier initiatives. It was clear to the researcher that there was little understanding of the philosophy of TPM by those interviewed. Only those aspects of TPM that needed to be done or completed next were really understood.

From an observation point of view during the first visit, the only visible examples of using lean concepts were 5S and storyboards. Although storyboards were positioned around the site, none were in the maintenance workshops. However, as these storyboards contained so little worthwhile information concerning maintenance, they were of little use to maintenance anyway.

The second visit to company E by this researcher was to observe changes within maintenance, with regard to lean concept use since the previous visit. For practical reasons since the last visit, the company to provide more realistic targets to aim for reassessed an earlier forecast for implementing lean within maintenance. Interviewees were becoming more aware and knowledgeable about the concepts that were being used. Nonetheless, the lean wastes example explained by this researcher did receive some blank looks from the interviewees. Visually, things had also changed. Although the maintenance function still had a centralised workshop without storyboards, those in the production areas contained more up to date and relevant information, useful to maintenance. The use of 5S within the workshop was certainly more noticeable, and more technicians were spending longer periods lineside. Teams were also being formed between maintenance and production to resolve some issues, e.g., recurring production problems (not quite EEM or NEPT teams though).

By the time the final visit was conducted by this researcher, it was noticeable that the practice of CI (although led by the supervisors) was being used more forcibly to encourage the adoption and use of the lean concepts. Integrated maintenance and production teams were now based lineside (just short of operator maintainers). The use of lineside trays and FIFO systems for 'non desirable' spare parts were now becoming more numerous in some areas of the plant. However, traditional methods of reporting faults were still very much in place (e.g. escalation) and, there was still no access to reliable or consistent performance data.

6.5.13 Summary of case study investigations

Each of the three major case study companies had different reasons for adopting and using lean concepts within their maintenance function. The least number of lean

concepts used (9) was by company C, the greatest number of concepts used was 14 by company B. Similarly, each major case company had different methods of data collection and management through their MMIS. Nonetheless, for the periods under investigation the use of lean concepts by the maintenance function of those investigated appeared to improve or maintain their effectiveness in all practically measurable areas of performance, both qualitatively and quantitatively. Qualitatively, users accepted the role of lean concept practice and considered certain elements useful. Quantitatively, the major case companies, where possible and recorded MMIS data were available, showed improved effectiveness in their activities during the period under investigation.

For the minor case study investigations, only qualitative information was usable. The usefulness of these studies was in monitoring the process of companies becoming perceivably more effective through the introduction and use of lean concepts within maintenance, and therefore to monitor the recognition of using newer approaches within the maintenance function.

6.6 Summary of chapter

This chapter described the use of an information template to address a research question, by way of a hypothesis to be tested through case study research within active maintenance organisations. It conveyed the investigations undertaken, from pre-case study company visits to assess the suitability and reliability of the researcher's approach and tools used, through to major and minor case study investigations to test the hypothesis.

The opportunity to provide feedback was given to all involved with this research. For the major and minor case study participants, copies of the final case reports as well as publications (one journal paper, one conference paper) directly related to this research were provided for comment and further discussion. As such, feedback from the pre- and case study participants concerning the research undertaken, and the investigation tools used are presented in Appendix D. Feedback regarding the publications, from those who received copies, or attended the conference presentation relating to the research are also presented in Appendix D.

Chapter Seven

Discussions and conclusions

7.1 Introduction

The purpose of this chapter is to further explain the case investigations undertaken in chapter six, in order to answer a research question through a hypothesis. Chapter seven also summarises the main issues drawn from the review of literature and relates these to the research question and hypothesis. Figure 7.1 provides a schematic outline of this chapter:

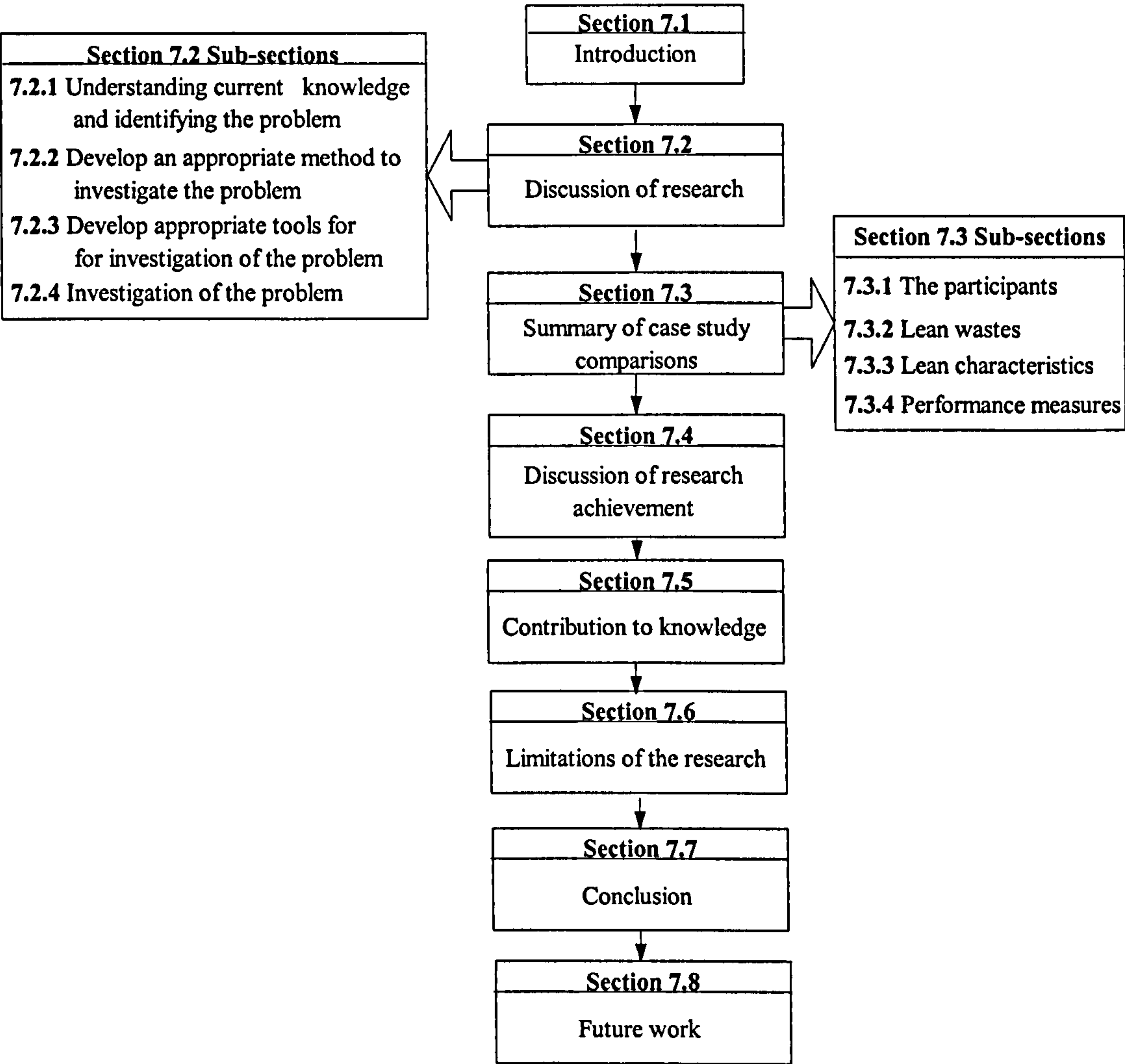


Figure 7.1 Outline of chapter seven

7.2 Discussion of research

Before comparing the major case studies within chapter six, it is necessary to summarise the main issues of this thesis. These issues not only provide the context in which the cross case comparisons are undertaken, but also the extent to which the research supports the hypothesis and contribution to knowledge.

In chapter one, the motivation for this research was expressed, in part by the outcome of preliminary survey research to identify if lean concept use beyond the scope of TPM were used by maintenance. The subsequent aim of the research was to understand ‘the contribution of lean thinking to the maintenance of manufacturing systems’. As summarised below, the remaining chapters can be categorised into four main objectives:

- 1 Understanding current knowledge and identifying the problem (i.e., review of literature and finding the gap in knowledge)
- 2 Develop an appropriate method to investigate the problem
- 3 Develop appropriate tools for investigation of the problem
- 4 Investigation of the problem.

7.2.1 Understanding current knowledge and identifying the problem

Chapter two presented and discussed the combined issues of manufacturing systems, maintenance, lean production, lean thinking, lean enterprise and measures of performance. Throughout the chapter, impartiality was sought by seeking and using standard definitions for those issues under discussion. Where possible, these definitions helped to explain within context, the practical and research implications within the research.

Research showed that maintenance overall has become a management issue, with a functional aim as that of a contributor towards an organisation’s profit. It also showed the need for maintenance to align with the business objectives, and hence perceivably increase value for an organisation. Likewise, lean concept use by organisations showed that those companies using four or more key lean tools, tended to have the largest increase in productivity and profitability than those that did not use lean tools. However, although lean concept use is becoming more commonly used, research could not identify a generic programme of lean concept implementation or use, or a

comprehensive list of lean activities practised by maintenance. In fact, despite many significant contributions and advances of lean thinking recorded through articles, books, and industrial examples, literature shows that maintenance regarding lean concept use beyond the scope of TPM has not been fully investigated. Similarly, from a maintenance perspective, prominent contributors have also advocated greater management and business integration. Nonetheless, excluding TPM, maintenance literature provides little or no insight into lean concept use by maintenance.

The gap in knowledge identified through the review of literature formed the basis of the research question: 'How does lean thinking improve the effectiveness of the maintenance function?' This question was then used to develop a hypothesis: 'Lean thinking improves the effectiveness of the maintenance function' and applied to the research as a basis for further investigation.

7.2.2 Develop an appropriate method to investigate the problem

Chapter three was used to present, discuss and develop a suitable method of investigating the research question through hypothesis. The practical option was to undertake case study research within active maintenance organisations, as it was clear that commercial operations could provide the richest source of data for investigation. It was also evident within the literature, that as this research would be the first of its kind, a novel approach had to be taken in the development of some research tools.

Developing an appropriate method to investigate the hypothesis also meant that careful consideration had to be given to the role of researcher. For practical reasons, the researcher's role was that of participant as observer, as this offered the best opportunity to minimise and confine the level of interaction and intervention during case research. The researcher's role was also reflective of the tools used to help investigate the research problem.

7.2.3 Develop appropriate tools for investigation of the problem

An appropriate method to investigate the research problem was presented, discussed and justified in chapter three. Similarly, in chapter six, preparation for the case research also provided a summary of the tools, techniques and definitions used to investigate the hypothesis. Additionally, chapters four and five were used to present and explain the development of two novel research tools to help the investigation.

The purpose of the first novel research tool, a lean concept reference framework in chapter four, was to comprehensibly represent lean thinking concepts possible within a company, and maintenance in particular. Its use, to help define lean concept presence within the companies visited as they may be applied to the maintenance function. Additionally, those concepts within the framework for which contribution to maintenance could possibly provide quantitative feedback, were reflected within the development of a measure for maintenance performance. This measure of maintenance performance as discussed in chapter five, included a number of indicators that signify change through maintenance activity. As such, the indicators themselves are not specific 'lean indicators' as they are index ratios directly related to maintenance practice.

7.2.4 Investigation of the problem

Chapter six and appendices A and B present the major case study research used to investigate the hypothesis. In context with the research aim, the tools and methods used to investigate the hypothesis were descriptive. The role of researcher? To gain an insight into the presence and possible contribution of lean use by maintenance. The use of research tools? To confirm the presence and possible contribution of lean concept use by maintenance. Prior to the case study investigations, the approach used by the researcher, and the tools used to investigate the research problem (i.e., hypothesis) were verified during six pre-case study company visits. Nonetheless, although flexibility was a main concern while investigating different types of company, with different management approaches and maintenance practice, assumptions could not be made concerning the operational diversity of those visited.

For the purpose of case study research, both qualitative and quantitative methods of information were sought to investigate the hypothesis. The aim of the qualitative research was to observe what was happening within real and active maintenance organisations in terms of lean concept use. The aim of the quantitative research (where or if possible) was to substantiate or otherwise, the qualitative research in terms of recorded maintenance performance. The main source for quantitative data came from sources such as maintenance management information systems (MMIS) used by the various maintenance departments that participated in the research, to record their activities. Interestingly, of all the companies approached to participate in the research, it was the automotive related companies who provided the richest source of both qualitative and quantitative data for investigation.

Using replication logic, three car companies were used to investigate the hypothesis as the main constituents of the case study research. Essentially, replication logic is where similar results are obtained from a number of different case studies, using identical methods of investigation for each case (external validity). According to Yin (1994) if replication logic is followed for a small number of cases, a study can be considered eminently feasible and be accepted for a much larger number of similar cases. With this in mind, two minor qualitative case study investigations were also undertaken, to highlight the process of becoming more effective through the introduction and use of lean concepts within maintenance.

The outcome of the major case studies showed that each company investigated had different reasons for adopting and using lean concepts within their maintenance function. Similarly, each company differed in the management and use of their performance data. Nonetheless, from a qualitative viewpoint all those investigated accepted the role of lean concept use within maintenance, and considered certain elements useful. Less straightforward however, was the use of the quantitative data retrieved from the MMIS of the participants.

It was found that the availability of the data types recorded by the different users determined the selection of usable performance indicators. The periods in which the data could be retrieved in relation to the implementation and use of lean concepts by maintenance was also a determining factor in this respect. For example, within the major case studies' findings, company A had started using TPM in 1996, however, MMIS performance data could only be retrieved for the period 1997 to 1999. On this basis, the use of quantitative data aimed to provide tangible evidence to emphasise the findings of the qualitative research.

Overall, for the periods under investigation, the use of lean concepts by the maintenance function of those investigated (i.e. companies A, B, C as major case studies) appeared to improve or maintain their effectiveness in all of the practically measurable areas of performance, both qualitatively and quantitatively. These practically measurable areas included the presence, use, perceived understanding / usefulness, and future use of lean techniques including waste elimination, and TPM/FTPM, continuous improvement, OEE, standards, Pokayoke, and root cause problem solving. In general terms therefore, the hypothesis 'lean thinking improves the effectiveness of the maintenance function' is shown to have been particularly true for the three major case study companies investigated. However, to answer the research question, and therefore justify the title of this thesis and substantiate the hypothesis further, a discussion of the major case studies through comparison is needed.

7.3 Summary of case study comparisons

The focus of this section is to emphasise the reliability of the research undertaken. In particular, how the individual experiences of the major case study companies (companies A, B and C) compare with each other, and how they relate to the initial research, the research question, and the hypothesis.

7.3.1 The participants

Each major case study company ascribed to the standard definitions and notion of what maintenance, maintenance management, and manufacturing systems were generally, but differed in their approach to a maintenance policy. However, the only noticeable differences between the cases themselves, and maintenance management issues presented in the literature review, were in areas of trade force flexibility, resources and administration structures. For example, Kelly's (1997) interpretation of trade force flexibility over the years (chapter two, Figure 2.5) shows how the maintenance workforce has changed from demarcation to that of operator-maintainer currently. In practice, only case company C showed clear signs of operator-maintainer practice, the other cases (A and B) were still heavily influenced by an inter trade approach to maintenance.

In the literature review, Kelly (1997) provides a representation of an appropriate resource (i.e., trade force) and administrative (i.e., trade force management) structure and example approach of resource allocation used by Nissan U.K (Figure 2.6 and 2.7). Regarding Kelly's resource and administrative structure, all of the case companies have integrated workshops for 3rd line maintenance. In terms of management structure, only case company B differs, in that it also has technical services personnel at supervisor and manager level as co-ordinators between production and maintenance. In relation to the Nissan approach to resource allocation, all the case companies have similar policies concerning 2nd line and 3rd line shutdown maintenance. Only company C has a similar 1st line maintenance – production policy approach.

Generally speaking, all the respondents within the case companies accepted the role of lean concept use and usefulness. However, perception of lean concept use, and the perceived benefits gained, differed between the different levels of personnel interviewed. The viewpoint of senior managers within the case companies was that lean use bought about or improved overall skills, and helped provide the basis of a more robust and standardised maintenance department. Nonetheless, concern was expressed concerning the difficulty in translating essentially lean manufacturing techniques to suit

maintenance. Junior managers placed greater emphasis on improved task flexibility, shared responsibility, improved quality and services, higher levels of innovation than previous, and better facilities overall. From the technicians' viewpoint, lean use meant less 'firefight' type maintenance, reduced skill demarcation, better levels of communication, and access to training.

7.3.2 Lean waste

Figure 4.2 in chapter four provides a representation of wastes possible within maintenance, analogous to the lean wastes proposed by Ohno (1988) and Bicheno (2000). This concept of lean wastes was then explained to interviewees within the case companies, who were then asked to identify similar wastes within their maintenance department and explain how they were tackled. Table 6.7 in chapter six highlights the case companies' responses and explanations.

It would not have been unreasonable of the researcher to expect that some lean practitioners could have matured beyond waste elimination, where prevention and containment were the dominant issues regarding processes and activities with a maintenance function. However, although all the major case companies understood the important issue of waste elimination, it was only really the managers who had a reasonable understanding of lean maintenance wastes. Furthermore, none of the case companies could envisage a situation where prevention and containment would be an issue.

7.3.3 Lean characteristics

From a practical point of view, different companies with different management approaches will formulate their own opinion of how maintenance should be applied within their own organisations. For the major case companies within this research, this was also true when regarding lean concept implementation and use. Fundamentally, rather than developing a maintenance strategy comprising lean approaches, an aggregation of various concepts were used to assist the maintenance of those investigated. This emphasised pre-study expectations that maintenance, as a function, is too technically and managerially diverse to mirror the actions of a perceivably lean (i.e., as advocated and practised by exponents such as, Womack, Jones and others) manufacturing environment exactly.

In terms of important lean concepts synonymous with successful manufacturers, and their perceived benefits as highlighted in chapter four, none of the case companies included Takt time or Kanban as part of their maintenance policy. Other lean concepts not as widely used, or even understood as the literature would suggest, were Kaizen, OEE, supplier associations and mapping, particularly for companies A and C.

In perspective, the use of lean principles such as waste elimination and 'value improvement' were shown to be relevant to those investigated. Other lean principles however, could not be shown to apply to maintenance, or simply deviated in their translation. For example, the practitioners' definition of what continuous improvement (CI) meant was much looser than, and differed from what the literature stated. Whereas, CI within the literature emphasised the philosophy of self-improvement and contribution, those investigated viewed CI as an ongoing summation of those lean principles already implemented and used. There was also evidence that some lean principles such as the value stream, Kanban, and the idea of flow may not have been suitable or workable when applied in practice. One particular reason for this is that it is virtually impossible with current knowledge to account for unplanned maintenance activities during the development of each lean principle approach. Another reason would be that the link between certain lean principles and the technical requirements of maintenance are also currently far too tenuous to see any perceived benefits for an organisation.

Overall, lean is a philosophy that consists of elements that aim at improving approaches to manufacturing. It is not necessarily an integrated approach or a replacement for any given manufacturing strategy, particularly for maintenance. However, the future development of additional lean concept use by maintenance practitioners may not preclude the use of techniques and approaches presently associated with lean manufacturing practice. Nonetheless, it may still be, or even for the future, that various interpretations of lean concept use may never be transferable to maintenance.

7.3.4 Performance measures

The use of performance indicators to measure the impact of lean concept use by the case companies within their maintenance are shown in Figure 6.13, chapter six. Based on available MMIS data, Figure 6.13 not only provides an indication of the types of data valued by the five case companies and how they differ from each other, but how the indicators reflect the contribution of lean concept use by maintenance.

To ensure the indicators presented were reflective of lean concept use, each of the case companies were investigated for alternate influencing factors (e.g., plant installation / age, manpower changes) that may otherwise be responsible for changes highlighted by the indicators. Subsequently therefore, the use and contribution of TPM toward the effectiveness of case companies A, B and C's maintenance were reflected by a reduction in the breakdown repair hours index in Figure 6.13. Similarly, for company B, the use of TPM also showed improvement within the evaluation of PM and predictive maintenance index. For the remaining indicators used, companies B and C benefited from the use of continuous improvement shown by the manpower efficiency index. Company B, the only user measurable in terms of OEE and standards, realised relative improvements in the equipment availability and maintenance hours applied indices. Improvement in the length of running index reflected the use of Pokayoke by companies A and B. Whereas the unscheduled tasks index reflected the efforts of all the case companies undertaking root cause problem solving.

In the research, it was found that many of the indicator ratios (Figure 5.3, chapter five) could possibly relate to the analogous maintenance wastes presented in Figure 4.2, chapter four. However, feedback during pre-case study visits suggested that a question relating to this issue might be too obvious to ask of the case companies. Subsequently this was not an issue that was raised by the researcher, or indeed recognised by any of the major case companies.

7.4 Discussion of research achievement

The literature review found that although extensive knowledge exists concerning lean thinking and maintenance, it does not refer to the issue of lean and maintenance beyond the scope of TPM. Motivated by this lack of information, this study sought to fill the gap in knowledge by satisfying the aim to understand the contribution of lean thinking to the maintenance of manufacturing systems. Expressed in the form of a research question the gap in knowledge was developed into a hypothesis as a basis for further research. To answer the hypothesis, research question and satisfy the aim a research methodology was adopted where the researcher developed two new tools alongside recommended methodologies for further investigation.

The suitability of the research approach and tools used were assessed during visits to six different companies by the researcher. These were then refined to reflect current lean and maintenance practice, and confirm that maintenance do use lean techniques beyond TPM; companies for case research were then approached. Although the tools and

methodology were not designed to be industry specific, companies with the richest source of data were sought.

Each company investigated was researched in an identical manner. Qualitatively, all were asked the same questions in terms of previous use, present and future use, and perceived benefits of lean concept use within and by maintenance. Quantitatively, each company's MMIS was interrogated for performance data, regarding all suitable maintenance activities that could be related to the indicators within the overall measure of maintenance performance. In particular, those data that could possibly relate to lean concept use by maintenance within the time period in which the concepts were used.

Practical and academic research, through the tools developed and the methodology used for investigation, have satisfactorily answered the research hypothesis and satisfied the aim of this research, particularly for those investigated. As such, it has been shown that by using waste elimination techniques, strongly associated with lean thinking philosophy, that lean thinking does improve effectiveness of the maintenance function. By waste elimination techniques, this refers to TPM, standards, Pokayoke, root cause problem solving, storyboarding visual management, 5S, continuous improvement, and Kaizen, etc. By using such techniques, improvement can be seen in such areas as reduced downtime, improved manpower efficiency, and the reduction in unscheduled tasks, etc., which also highlights the contribution of lean thinking to the maintenance of manufacturing systems. Furthermore, logic replication would also suggest that for those investigated, the hypothesis would likewise be applicable for a larger number of similar cases also.

7.5 Contribution to knowledge

The aim of this research has been to answer the research question through hypothesis, and thereby contribute to knowledge. As reference could not be made within existing literature or practice to answer aspects of the research question and hypothesis, two novel research tools were developed. Although these tools were a means to an end, they provided a significant contribution to the research. The major contributions of the research are presented here:

- 1 This research confirms that knowledge of lean thinking and lean concept use, beyond the scope of TPM are both utilised by maintenance. By exposing an area of previously unexplored research, it has also addressed the important issue of maintenance within a business context by adding to earlier business focussed

research / work. Furthermore, it has also provided a foundation for the transfer of knowledge and understanding from a successful manufacturing focussed business function, to that of maintenance as a contributor to business focussed organisations.

- 2 This research has given an 'as is' view of lean thinking and maintenance, particularly within the U.K automotive industry. It exposes the diversity of maintenance as a function within this industry, and the scope of lean concept use and understanding within these functions. It also shows how maintenance in terms of lean development falls very much short of the perceptions portrayed by various lean proponents and practitioners, whose focus is manufacturing and production. Nonetheless, it has also shown that lean concept use is not exclusive to any particular style of maintenance, and that the benefits of use are applicable within industry generally. As such, this research also provides a reference that will allow researchers and academics to fill the gap in literature concerning 'lean and the maintenance issue'.
- 3 This research showed that a generally agreed point of reference, or programme of lean concept use, did not exist for maintenance. As such, a reference framework representative of lean concepts possible within a company and maintenance in particular was developed. This framework provides a level of lean concept understanding, outlines the perceived benefits of lean concept use, and how they may be measured. Overall the lean framework serves at least three general purposes:
 - Provides scope and definition for the investigation of lean concept use by maintenance
 - Reduces errors of pre-judgement through flexible representation of the lean concepts possible within companies and maintenance
 - Provides a schema to develop appropriate and responsive forms of measurement that suits different conditions and situations.
- 4 The research showed that the use of maintenance performance indicators could provide quantitative support to the perceived benefits of lean concept use by maintenance. As such, an overall measure of maintenance performance was developed, comprising indicators related to the various maintenance tasks undertaken within a company, and those activities that could relate to lean concept use. Overall, the measure was designed to be fully comprehensive and modular, to

compensate for the different types of maintenance function under investigation. It was also developed to accommodate the different methods and style of maintenance data collection. A top-down approach, through an overall indicator (following subsequent indices, to individual indicator indexes), allows the business to assess the performance of the maintenance function. As the framework is hierarchical and simple, business managers should be able to drill-down to identify root causes within the indices they use. Escalation from the indicator indices not only provides frontline maintenance activity feedback, but also provides a clear perspective of how they are being effectively used by the business.

7.6 Limitations of the research

The various contributions of this research have been presented and discussed. However, limitations can be raised against this research and are summarised here.

Ideally, the scope of this research would have extended beyond the automotive industry to include the maintenance of other industries, and indeed suppliers. However, to construct the reality presented as 'as is' within this research for all industry sectors, would have been almost impossible to replicate, particularly in terms of the time involved and sufficiency of research participants.

Perhaps a more incisive view of lean and the maintenance issue could have been gained by first implementing various lean concepts within a maintenance function, then measuring the impact of their contribution over a period of time. However, this approach is clearly impractical within the scope of this research. Firstly, the outcome would have been unique rather than generic. Secondly, the time scale involved with lean implementation would go far beyond the limit of this research.

The use of maintenance performance indicators integrated within an overall measure of maintenance performance, although highly useful, and very well received by those investigated, were limited by data availability for population. As such, in retrospect it may have been easier to use some form of meta-technique to investigate the quantitative contribution of lean concept use by maintenance. However, it is also likely that any form of generic meta-technique could only support a unique outcome for a particular organisation.

7.7 Conclusion

In 1990, Womack, Jones and Roos summarised the state of advanced manufacturing practices for that period. By 1996, Womack and Jones had renewed and extended their message to present a set of principles as an antidote to waste within organisations; this antidote was subsequently termed 'lean thinking'. Their aim? A comprehensive business logic to provide manufacturing with logical ways of pursuing value to its maximum potential, through improved productivity, quality, availability, performance and efficiency at lower cost.

From the maintenance perspective, the increased demands from manufacturing for improved productivity, quality, and availability has meant that maintenance has now become a major management issue, expected to add value to an organisation through greater management integration. The management issues that link both manufacturing and maintenance are fundamental characteristics of lean thinking. However, despite many significant contributions and advances of lean thinking recorded through articles, books, and industrial examples, the maintenance function beyond the scope of TPM has not been fully investigated. Similarly, from a maintenance perspective, excluding TPM, little or no insight into the use of lean thinking concepts by maintenance has been provided, despite prominent contributors advocating greater management and business integration.

The lack of evidence in literature, that suggests lean thinking had not been seriously considered within maintenance, was addressed by this thesis. Accordingly, this thesis highlighted and discussed the combined issues of manufacturing systems, maintenance, lean production, lean thinking, lean enterprise and measures of performance through examination of related practical and academic views and concepts. It provided a valuable insight to the current issue of maintenance within a business context, by confirming that lean concepts beyond the scope of TPM are understood and used by maintenance, and contributes to the effectiveness of an organisation.

The concept and use of lean thinking is aimed at adding value to an organisation. The maintenance function is also expected to add value through its activities. This has been shown by this research. However, it should also be noted that Lean is a set of tools rather than a coherent strategy, so while some of the tools might be very useful as part of an integrated maintenance strategy, lean principles alone cannot form the basis of a maintenance strategy. Nonetheless, a lot of work still needs to be done to understand more fully the presence, use, usefulness, and contribution of lean thinking, not only to

the maintenance function but as part of an inclusive organisation. Some suggestions based on this research and the limitations uncovered are discussed below.

7.8 Future work

The contribution of this thesis, and the knowledge gained from the research undertaken, should be used to address the limitations discussed earlier. Future research should be expanded to include more diverse industries than just maintenance within the automotive industry.

The focus of the next stage of research should begin with further examination of the lean inter-organisational links between maintenance and other areas within the business. This may encourage further investigation of how maintenance may become a more inclusive business focussed component of an organisation.

Another logical step to pursue would be to use this thesis as a primer for selecting those lean concepts known to work for maintenance already, then introducing them into like companies not already using them. Beyond this basic approach of standardising lean presence and use within maintenance, intervention can then be used to strengthen the contribution of those concepts already being used, and form the basis for introducing other lean concepts. Based on the findings of this research, concept improvement and additional implementations would ideally start with such core concepts as mapping and Kaizen. Future work may also extend beyond the focus of individual maintenance functions within organisations to include lean concept use and standardisation throughout the maintenance supply / value chain.

The benefits of using the overall measure of maintenance performance have already been expressed. Nonetheless, the reduction of the performance indicators to a few significant parts, would make them more practically useable to future work. This can be achieved without too much difficulty or loss of flexibility, detail or integrity, as the measure was purposefully developed to over compensate for the different types of data recorded by different organisations. However, it may also be shown in the future, that a Meta technique could be more appropriate for a particular organisation seeking a unique solution to any number of issues, then a new area of research can be undertaken to address this approach. It is obvious, and not just from the observation made during this research, that different companies adopt different management techniques within their maintenance, therefore research will need to either accommodate or compensate for this.

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Appendix A

Case study investigation of the maintenance function within company A

A1 Introduction

Case study research is used to investigate the impact, practical use, and usefulness of lean concept use within the maintenance function of an automotive final assembly manufacturer. Specific attention focuses on the combined issues of lean, maintenance, and performance measures to identify the impact of lean concept use within maintenance. The investigation process conducted over three visits, involved interviews, observations, and data collection from a maintenance management information system (MMIS) used by maintenance. The interviewees were two maintenance managers, one of whom is the lean initiative project leader, one maintenance supervisor, and a technician involved with recording maintenance activities. Overall the company employs approximately 2500 people on site, of which maintenance accounts for 100 personnel.

Qualitative and quantitative methods of information are used to help identify the practical use, usefulness, and impact of lean thinking within maintenance. Quantitative analysis will seek to provide meaningful information of raw data retrieved from sources such as the MMIS used by the company. Qualitative analysis, through semi-structured interviews and observation, will help to determine the level of practical use and perceived usefulness of lean thinking approaches used by the maintenance function. The following hypothesis is used as a basis for this investigation: *Lean thinking improves the effectiveness of the maintenance function.*

The maintenance function under investigation was known to use a range of lean thinking techniques before this investigation. However, assumptions could not be made concerning the scale of lean, or use of performance measures. As no comprehensive list of lean activities or performance measurements used by the maintenance function were identified or referred to, an alternative methodology was used. As such, a lean reference framework and overall measure of maintenance performance developed by this researcher is used as a reference for investigation. Only explanation of the lean issues and related performance indicators derived from the overall measure of maintenance performance concerning this investigation are presented here.

A2 Identification of lean practices used by the maintenance department

A2.1 Interviews and observations

Semi-structured interviews and visual checks were conducted to determine the level of use, and to understand the application of lean thinking practices from a maintenance perspective. The participants questioned were given a brief description of the lean practices possible within a company, and maintenance in particular, with an explanation of terminology and clarification of the issues. Table A1 summarises the lean activities used by the maintenance function under investigation and the year of implementation.

Lean thinking concepts	Approximate start year	Observed in use
Standards	1996	✓
Pokayoke	1996	✓
Root cause problem solving	1996	✓
Process activity mapping	1996	✓
TPM	1996	✓
Inventory management	1999	✓
Story boarding	1999	✓
Visual management	1999	✓
Self audits	1999	✓
5S (CANDO)	2000	✓
Continuous improvement	2000	✓

Table A1 Lean thinking techniques / approaches used by the maintenance department

A2.2 Lean techniques used

Standards (Bicheno, 2000). ISO 9000 and ISO14001 are followed by maintenance. Both the company and maintenance align themselves with continuous improvement (CI) approaches. Maintenance personnel are encouraged to standardise their work, e.g., list activities, sort them into repeating and irregular activities, standardise the repeaters, and then standardise the irregular activities into blocks. Skill matrix charts are also used to identify current capability and future training needs, but the concept and practice of standards are still developed and driven by management.

Pokayoke (mistake proofing) (Shingo, 1989). For this company Pokayoke is closely tied with the process of root cause problem solving. Root cause problem solving focuses on the 5 whys etc., whereas Pokayoke involves teams undertaking early equipment management (EEM) and new equipment procurement (NEPT) procedures. These teams

are biased toward automated mistake prevention for production and are involved with the commissioning of new accessory equipment to the line.

Root cause problem solving (Bicheno, 2000). Considered a standard procedure root cause problem solving has been present within the company since pre-lean implementation. A parallel method of the 5 whys approach is used by maintenance in addition to vendor feedback reports for problematic issues. Overall, root cause problem solving and Pokayoke (mistake proofing) for this company are similar in practice.

Process activity mapping (Bicheno, 2000). Process activity mapping is used by maintenance, but only really for major overhauls and shutdown maintenance. Ordinarily, process activity mapping for maintenance is the responsibility of maintenance planning.

Total productive maintenance (TPM) (Nakajima, 1988). The introduction of TPM within this company coincided with the phasing out of trade demarcation within maintenance and the introduction of team based multi trade functions. TPM has evolved from awareness training through local responsibility, to low level escalation practices, although many PM activities are still carried out by maintenance during non-production hours.

Inventory management (Bicheno, 2000). The interpretation by maintenance of inventory management from a lean perspective has been in place since 1999. Initial guidelines were put in place for maintenance to follow and have been kept to generally. Currently, a rotational first in first out (FIFO) system is in place for bearings, seals etc.

Story boarding (Bicheno, 2000). Storyboards are used throughout the company and maintenance function. Maintenance efficiency updates are posted on a weekly basis throughout the site, with section managers and supervisors being e-mailed project updates, quality improvements, control charts etc., on a weekly basis also.

Visual management (Henderson and Larco, 1999). Visual management is encouraged within maintenance, and was the starting point for the introduction of 5S (CANDO) and CI within maintenance. Skill matrix charts are being used as well as improved flagging systems (i.e., auto fault register, Andon lights). Additional visual management tools are planned or have already been implemented, such as improved information retrieval, clarity of task involvement and ongoing standardisation. However, GEMBA (shopfloor innovation) has yet to be a commonly used philosophy within maintenance.

Self-audits (Bicheno, 2000). Initial attempts at self-assessment questionnaires within the maintenance department were very poorly received and subsequently phased out. However, management as part of a wider corporate assessment conduct performance audits.

5S (CANDO) (Monden, 1994). 5S was introduced more formally within the plant to coincide with a decentralised maintenance policy, i.e.; the maintenance technicians went trackside. The company emphasis of the 5S approach is also enforced, as previous endeavours tended to lack momentum.

Continuous improvement (CI) (Bicheno, 2000). CI is the ongoing summation of previous and introduced lean concepts to the company. The concept and encouragement of CI concerning maintenance is management led and requires more time for it to fully succeed. Acceptance of CI is inhibited by the retention of traditional methods of reporting (i.e., escalation, technician to supervisor to manager etc.), which management are trying to presently overcome.

A2.3 Additional recorded comments

In addition to answers given during the questioning, some notable comments were recorded:

“Overall equipment effectiveness (OEE) is not used by the maintenance department, but has on occasion been used by production. Maintenance would consider using OEE if a new assembly line were introduced, but prefer measuring mean time to failure (MTTF) in the production environment. “The assets within the production area under investigation have been in place since 1993, so we feel that we would be wasting our time measuring OEE within a well understood process”. (*Manager*).

“The introduction of work practices (*i.e., TPM etc.*) has not unduly affected maintenance in terms of staff turnover, which remains less than 2%. Overall, the practices that have been accepted by the workforce are viewed as additional tools to help them with their jobs”. (*Manager*).

“In fairness, some of the approaches we now use, described as lean practices (*i.e. root cause problem solving etc.*) have been used in some form or another for many years. They are a combination of practices previously used that have been combined to form a more common sense approach to the problems we previously had”. (*Managers*).

A2.4 Observations

Visual checks of the maintenance function and production line were conducted over two visits. The site has a dedicated administration centre on the shop floor co-ordinating the manufacturing systems operations. The use of 5S was evident throughout the plant and maintenance areas, although it did fall short of a clean desk policy within office areas. Issues concerning TPM activities, responsibilities etc., were shown on storyboards (see Figure A1 and Figure A2 for examples) throughout the factory, but not as visual machine-side record sets. Storyboards were positioned throughout the factory and satellite maintenance areas, providing up to date information on: quality / environmental / standards, training, fishbone diagrams, activity updates, top ten losses, trend charts, project outlines and action plans. As part of the visual checking process a manager also provided documentation concerning skills matrix charts, NEPT and EEM practices, and vendor feedback documentation as used by maintenance.

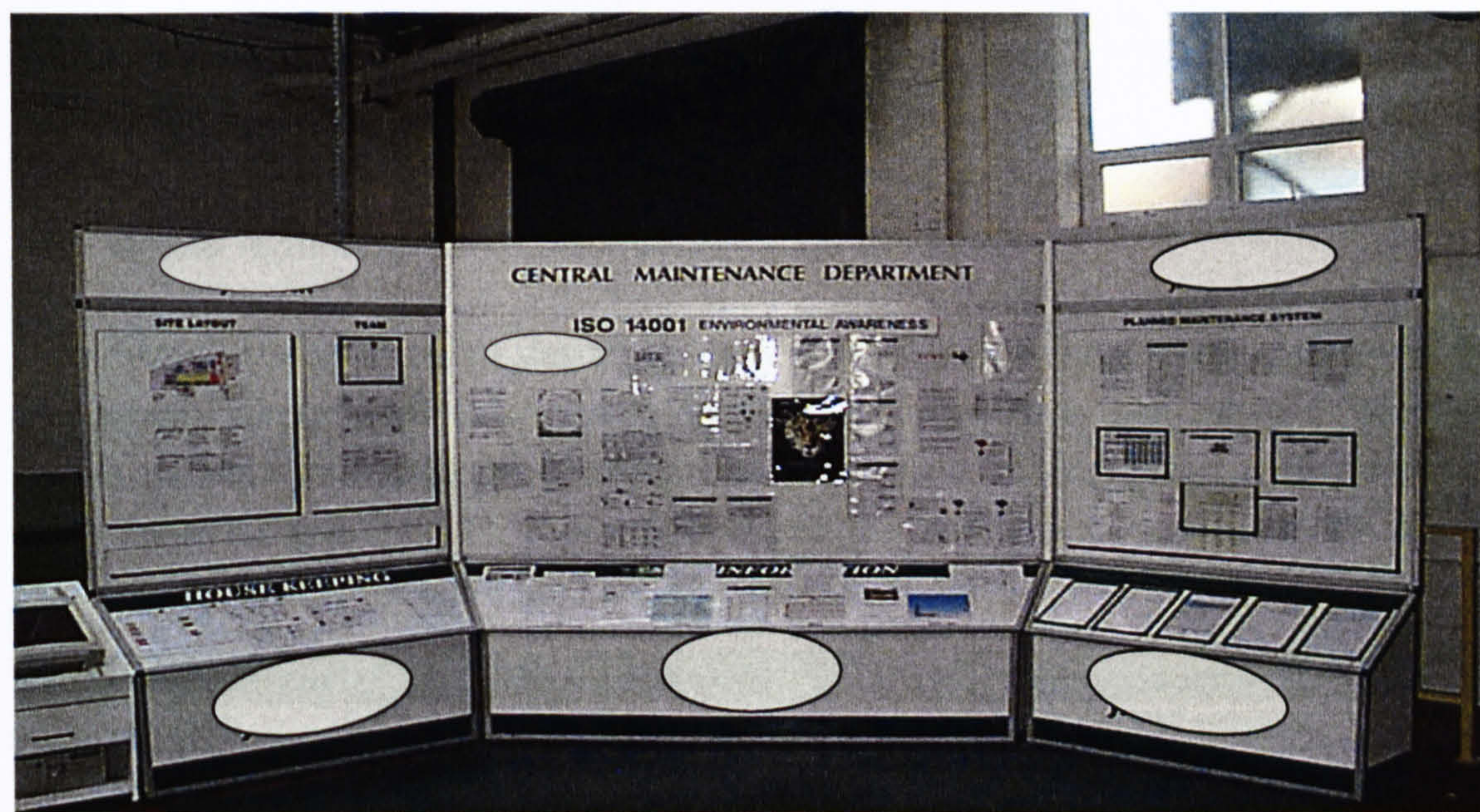


Figure A1 Storyboards for maintenance

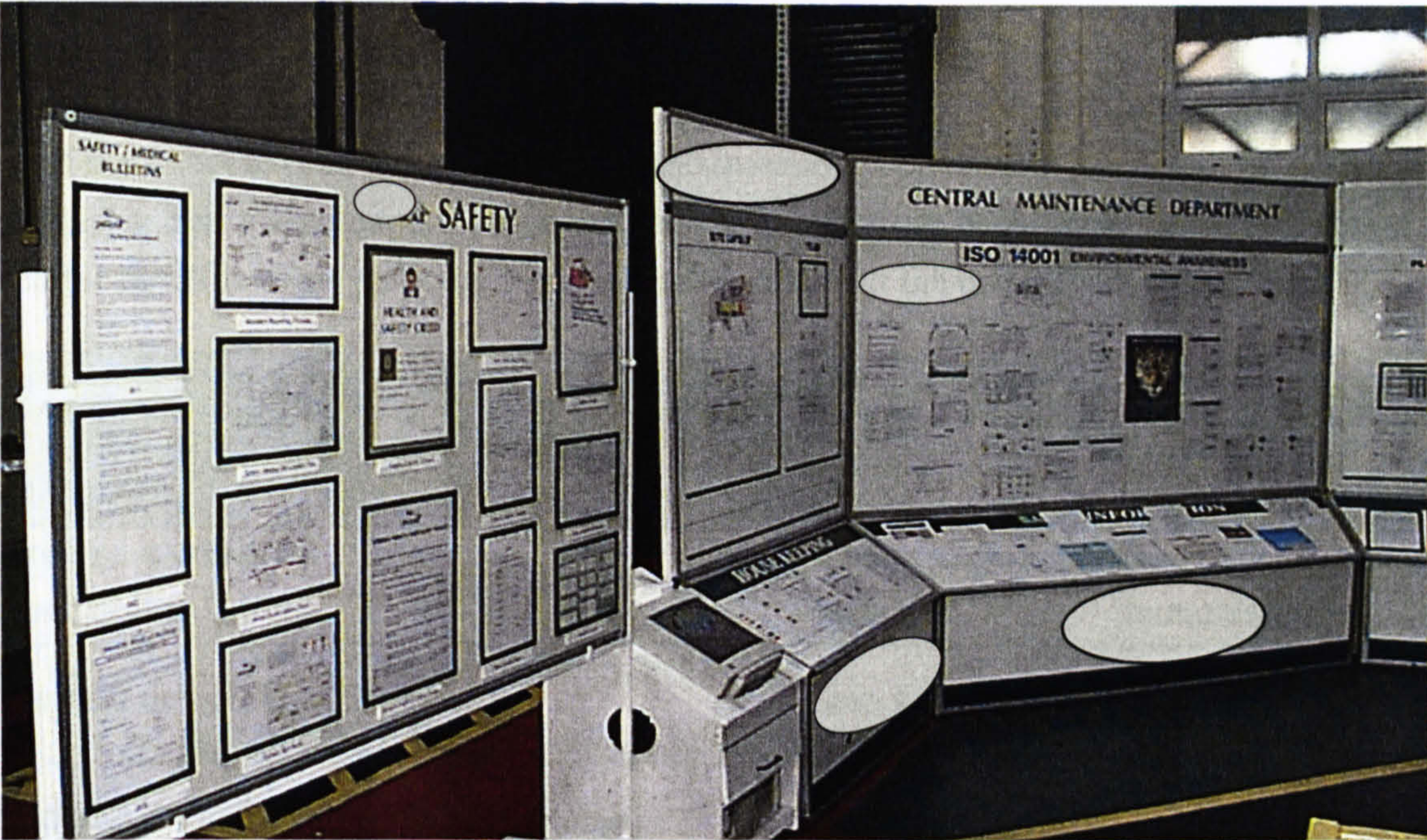


Figure A2 Storyboards for maintenance

A2.5 Waste reduction within the maintenance function

Lean manufacturing literature describes many types of waste that are identifiable within a company. These were explained to interviewees who were then asked to identify similar wastes within their own maintenance department and explain how they tackled them. Table A2 highlights the production wastes, the maintenance wastes identified and explanations of how the latter are tackled within the company.

Production wastes	Maintenance wastes	How maintenance wastes are tackled
Overproduction	Excessive PM activities	Planned / scheduled PM activities
Waiting	Waiting for resources	Satellite workshops / stores, lineside trays etc.
Transporting	Centralised maintenance	Decentralised lineside maintenance
Processing	Excessive TPM activities	Escalation capping, (i.e., capability guidelines)
Inventory	Excessive stock	FIFO spare parts
Motions	Could not define	Could not define
Defects	Poor maintenance	Skills matrix, EEM / NEPT teams
Human potential	Lack of training	Skills matrix, taught courses
Inappropriate systems	Poor information	Automated fault systems, training
Energy and water	Energy management	ISO 14001
Materials	Poor re-design	NEPT / EEM teams
Service and office	Could not define	Could not define
Customer time	Poor procedures	Standards / Storyboarding
Customer defection	Poor maintenance	Skills matrix, Training

Table A2 Production wastes, maintenance wastes and tackling the maintenance wastes

A2.6 Response to questions

All of the interviewees were asked the same questions concerning their opinion of lean thinking within maintenance. Table A3 shows the response to the question, “what have been the benefits of introducing various lean concepts to the maintenance function?”

Manager 1	Manager 2	Supervisor	Technician
Increased workforce responsibility	Reduced downtime	Clearer task definitions	Less skill demarcation
Less skill demarcation	Fewer unscheduled tasks	Less firefighting	Greater team responsibility
Increased throughput	Waste reduction	Better communication	Better communication
Less firefight maintenance	Decentralised maintenance	Better facilities	Better access to information
Standardised procedures / activities	Improved management, team and production communication	Quicker breakdown response	Less firefight maintenance
Greater product awareness	Faster response times	Easier access to spare parts	Less unscheduled tasks
Work team unity	Automated fault system	Access to further learning	Less time spent machine minding

Table A3 Response to question: “What have been the benefits of introducing various lean concepts to the maintenance function?”

Table A4 shows the responses from the question “Has there been a downside to the lean concepts used within the maintenance function?”

Manager 1
“Yes: Lack of understanding and unwillingness of some to accept changes concerning lean practices use. Difficulty in translating essentially production led lean techniques to suit the maintenance function. Initial reluctance to share maintenance knowledge with production. Still waiting for shopfloor revolution and leadership for change”.
Manager 2
“Managing lean implementation or innovation is not really my area of expertise so I would not really know if there has been an overall downside. However, there have been various activities suggested or implemented that have not really been successful in terms of acceptance or workability”.
Supervisor
“I do not have any direct input for the introduction of lean thinking activities within the maintenance department. I am kept informed of the successes through storyboards and e-mail updates but not so much the non-starters”.
Technician
“Not really, a few teething problems here and there and a couple of non-starters, but on the whole ok”.

Table A4 Response to question: “Has there been a downside to the lean concepts used within the maintenance function?”

Interviewees were asked their opinion on the continued use of lean concepts within their maintenance department and how they viewed the future growth. Table A5 shows the responses from this question.

Manager 1
“Consolidate the more recently accepted lean practices, introduce greater decision making autonomy, i.e., change / idea start-ups etc. Integrate maintenance more with manufacturing production, i.e., as facilitators of continuing first line and EEM maintenance solutions”.
Manager 2
“Introduction of line side shadow boards, better information systems, and improved skills acquisition for technicians”.
Supervisor
“I would like to see more organisation transparency”.
Technician
“See what happens”

Table A5 The future of lean practices within maintenance?

A3 Measuring the performance of the maintenance function

A3.1 Company measures for maintenance

The company does not directly measure the overall performance of the maintenance function. Its bottom line measure for maintenance performance has traditionally been throughput, i.e., has the volume of cars manufactured increased or decreased? If the volume has decreased, what are the reasons? From a maintenance perspective, measurements are operational and focus on improvement and reduction of production downtime.

The company, as part of a global organisation, currently uses a unified Intranet based system to record certain aspects of their maintenance activities, and although the maintenance is split into zones all the recorded data is combined. The previous system (an MMIS) was customised to suit the needs of the maintenance function and provided zone-based data output.

A3.2 Conditions of measurement

Internally, metrics involving cost data was not available, so cannot be used. External server problems with the current maintenance management system also prevented analysis of recent data.

A3.3 Measurement focus

The maintenance function comprises of six zones, each accountable for measuring its own performance. Some zones are more reliable than others, with the poorest recording less than 50% of its activities. The most reliable zone, with the highest level of reporting consistency, was trackside maintenance. The primary production equipment within trackside maintenance had been in place since 1993. In line with the rest of the maintenance department, trackside has a low staff turnover rate, nominally less than 2% per annum throughout. Overall therefore, the focus of investigation regarding performance measurement centred on the area of trackside maintenance.

A3.4. Measurement period

The period of measurement extends from January 1997, shortly after implementing TPM through to June 1999. Thereafter data becomes less consistent and reliable, in part as a result of introducing a new maintenance information system that suffered loss of data. The age of the primary trackside equipment, installed in 1993, during the measurement period was considered neither too new nor old to exhibit early or late life failure modes that may otherwise distort readings.

A3.5 Performance indicators used

Based on three criteria: ease of data retrieval, cost of retrieval and ease of understanding the results, a spreadsheet application was used to calculate an output for the performance indicators used for this investigation.

Table A6 summarises the appropriate performance indicators chosen for this investigation, based on the lean techniques used and availability of data from the MMIS used by maintenance.

Performance indicator	Indicator calculation	Desired outcome
Breakdown repair hours	$\frac{\text{No. hours spent on breakdowns}}{\text{Total direct maintenance hours}}$	Trend decrease
Length of running	$\frac{\text{Tot Prod. output in units or hrs}}{\text{Qty repairs for same period}}$	Value increase
Unscheduled tasks	$\frac{\text{Man-hrs unscheduled jobs}}{\text{Total maintenance hours}}$	Trend decrease

Table A6 Maintenance performance indicators used for this investigation

The indicators presented in Table A6 are used to indicate the impact of using the lean concepts presented in Table A1, and the subsequent impact they may have upon the maintenance function. However, for this research, only three of the eleven techniques presented in Table A1 could be investigated. These are: TPM, Pokayoke and root cause problem solving.

A4 Output results

Based on the available information provided by maintenance, Figures A3-A5 represent the values of the performance indicators shown in Table A6. For the maintenance function within this company, emergency events were classified with other unscheduled events, such as line stoppage. All emergency tasks were categorised as breakdown tasks or repairs.

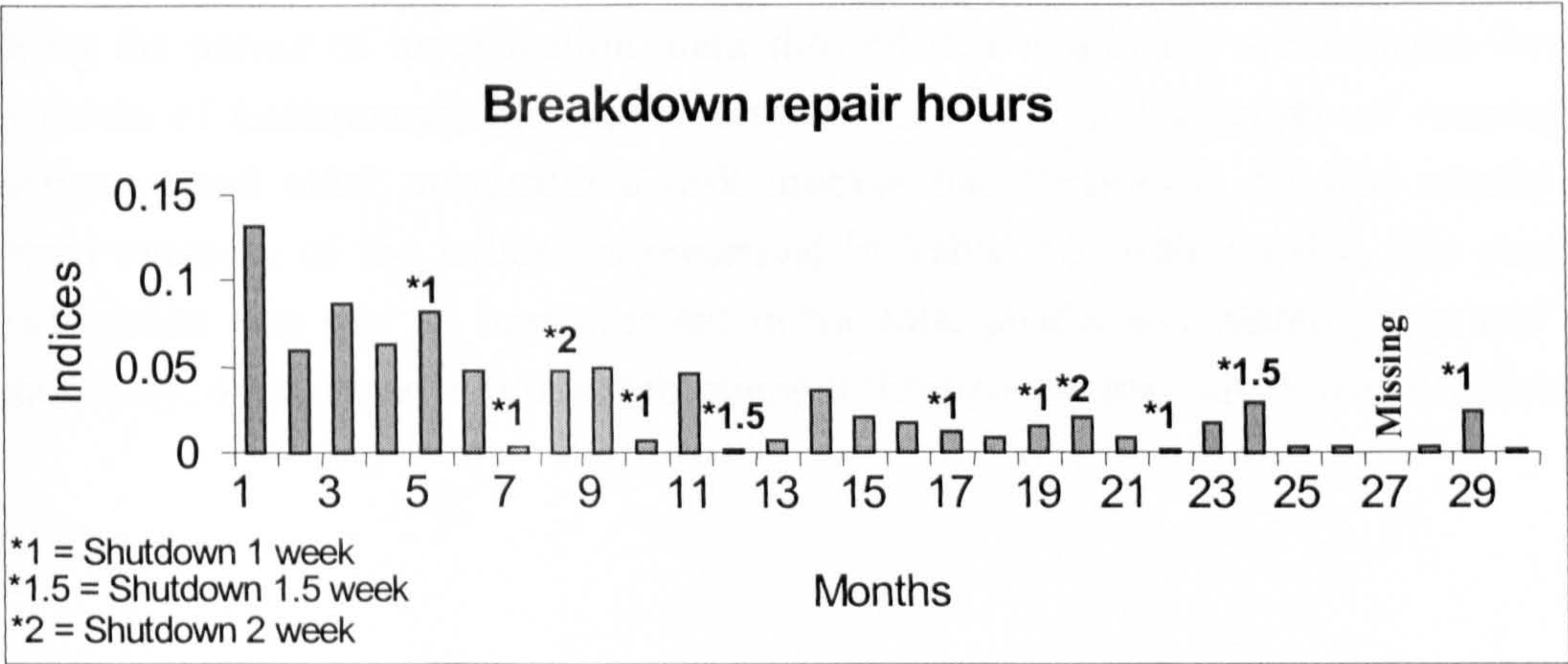


Figure A3 Breakdown repair hours index, January 1997 to June 1999

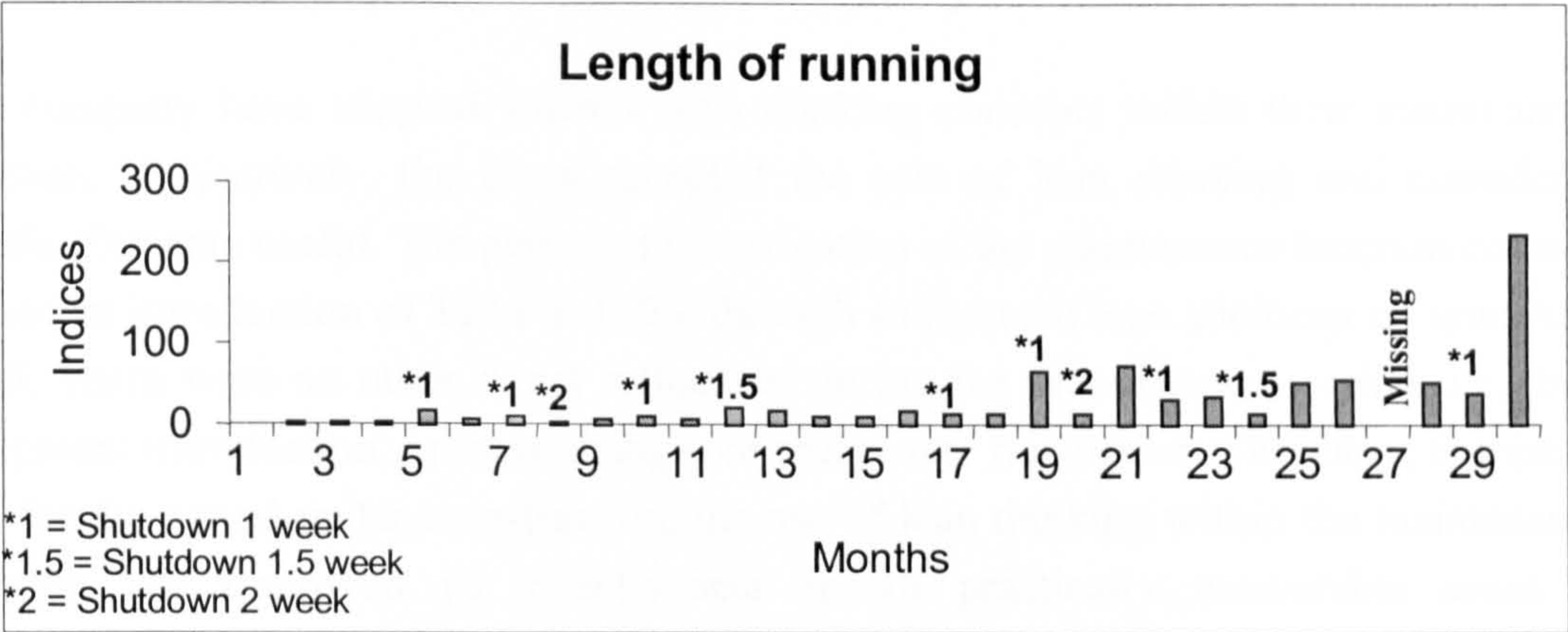


Figure A4 Length of running index, January 1997 to June 1999

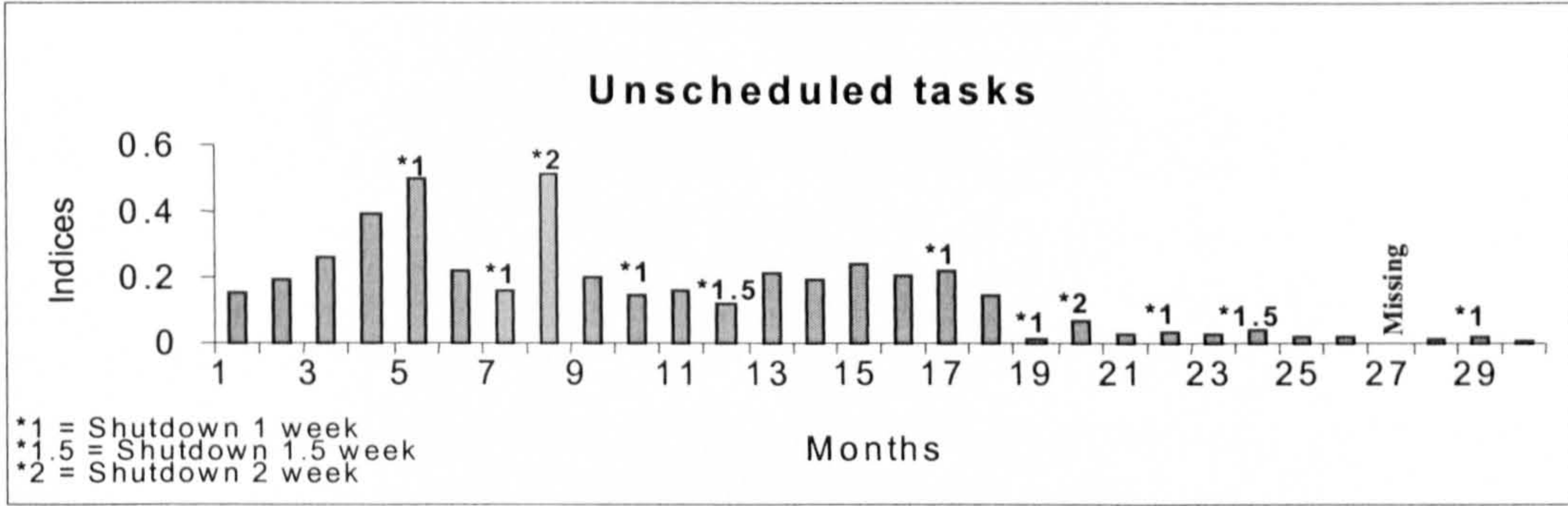


Figure A5 Unscheduled tasks index, January 1997 to June 1999

A4.1. Summary of results

During the period of investigation, data showed that within the maintenance function the levels of (manpower) utilisation, breakdown repair hours, length of running and emergency and other unscheduled task indexes had improved. All had satisfied the desired outcome of the indicators presented in Table A6. Additionally, this period of investigation also saw an improvement in the total production running time and most importantly, an increase in product throughput through the zone under investigation.

A5 Overall summary of company A case study

The company have adopted various lean thinking concepts within their maintenance function. Subjectively, the users accepted the role of lean thinking and considered certain elements useful. The period of investigation of the maintenance function covered the recent introduction of TPM in 1996, through subsequent lean additions up unto June 1999. There were no other direct influences during the measurement period, i.e., new equipment introduction, process changes or manpower fluctuation. Therefore, it appears that for the period under investigation, the use of lean thinking within the maintenance function has improved its effectiveness in all practically measurable areas of performance.

Appendix B

Case study investigation of the maintenance function within company B

B1 Introduction

Case study research is used to investigate the impact, practical use, and usefulness of lean concept use within the maintenance function of an automotive final assembly manufacturer. Specific attention focuses on the combined issues of lean, maintenance, and performance measures to identify the impact of lean concept use within maintenance. The investigation process conducted over three visits, involved interviews, observations, and data collection from a maintenance management information system (MMIS) used by maintenance. The interviewees included the head of maintenance, an operations manager, a technical services manager, two maintenance engineers involved with recording maintenance activities, and a maintenance engineer focussing on technical support. Additionally, opinion was sought from two production operators concerning their involvement in improvement activities. Overall the company employs approximately 9000 people on site, of which maintenance accounts for 130 maintenance within the two manufacturing assembly works under investigation.

Qualitative and quantitative methods of information are used to help identify the practical use, usefulness, and impact of lean thinking within maintenance. Quantitative analysis will seek to provide meaningful information of raw data retrieved from sources such as the MMIS used by the company. Qualitative analysis, through semi-structured interviews and observation, will help to determine the level of practical use and perceived usefulness of lean thinking approaches used by the maintenance function. The following hypothesis is used as a basis for this investigation: 'Lean thinking improves the effectiveness of the maintenance function.'

The maintenance function under investigation was known to use a range of lean thinking techniques before this investigation. However, assumptions could not be made concerning the scale of lean, or use of performance measures. As no comprehensive list of lean activities or performance measurements used by the maintenance function were identified or referred to, an alternative methodology was used. As such, a lean reference framework and overall measure of maintenance performance developed by this researcher was used as a reference for investigation. Only explanation of the lean issues

and related performance indicators derived from the overall measure of maintenance performance concerning this investigation are presented here.

B2 Identification of lean practices used by the maintenance department

B2.1. Interviews and observations

Semi-structured interviews and visual checks were conducted to determine the level of use, and to understand the application of lean thinking practices from a maintenance perspective. The participants questioned were given a brief description of the lean practices possible within a company, and maintenance in particular, with an explanation of terminology and clarification of the issues. Table B1 summarises the lean activities used by the maintenance function under investigation and the year of implementation

Lean thinking techniques	Approximate start year	Observed in use
Standards	1998	✓
Pokayoke	1998	✓
Root cause problem solving	1999	✓
Process activity mapping	2000	✓
TPM	1996	✓
Inventory management	1996	✓
Story boarding	2000	✓
Visual management	1996	✓
5S (CANDO)	1996	✓
Continuous improvement	1997	✓
Kaizen activities	1997	✓
Overall equipment effectiveness (OEE)	1997	✓
Supplier associations	1997	✓
Mapping (human, resource)	2001	✓

Table B1 Lean thinking techniques / approaches used by the maintenance department

B2.2 Lean concepts used

Standards (Bicheno, 2000) ISO 9000 and ISO14001 are followed by maintenance. Both the company and maintenance in particular align themselves with continuous improvement. Maintenance personnel are encouraged to standardise their work, i.e., sort activities into repeating and irregular activities, then standardise the irregular activities into blocks. Skill matrix charts are also used to identify current capability and future training needs

Pokayoke (mistake proofing) (Shingo, 1989). Pokayoke involves teams undertaking early equipment management (EEM) and new equipment procurement (NEPT) procedures. These teams are biased toward automated mistake prevention for production and are involved with the commissioning of new accessory equipment to the line. Teams are made up of, technical services, maintenance and operators. For large-scale projects concerning equipment installations vendors and suppliers are also involved.

Root cause problem solving (Bicheno, 2000). This methodology has been used by the company since pre-lean implementation, and is considered a standard procedure. A parallel method of the 5 Why's approach is used by maintenance in addition to vendor feedback reports for problematic issues. Overall, root cause problem solving and Pokayoke (mistake proofing) for this company are similar in practice.

Process activity mapping (Bicheno, 2000). Process activity mapping is used by maintenance, but developed and co-ordinated by technical services. It is used by maintenance for major overhauls, shutdown maintenance, and production projects.

Total productive maintenance (TPM) (Nakajima, 1988). TPM was reintroduced more forcefully within the company since 1998-1999 as previous attempts lacked long term support. Although many PM activities are still carried out by maintenance, production, integration, and awareness training through local responsibility, to low level escalation practices are taking place.

Inventory management (Bicheno, 2000). The interpretation by maintenance of inventory management from a lean perspective has been in place since 1995 / 1996 through the introduction of 'bonded stores'. However, since 1998-1999 rotational first in first out (FIFO) systems for bearings, seals, consumables etc., have been used. Additionally, vendor and supplier associations have been in place since 2000 to ensure better spare part replacement reliability, and collaboration during improvement and new project developments.

Story boarding (Bicheno, 2000). Storyboards are used throughout the company and maintenance. Maintenance updates are posted on a weekly and monthly basis throughout the site. All those interviewed were pleased with the contribution storyboards had made to overall awareness.

Visual management (Henderson and Larco, 1999). Visual management techniques are used and encouraged within maintenance, and were the starting point for the

introduction of 5S and continuous improvement within maintenance. Additional visual management tools such as improved information retrieval, clarity of task involvement and ongoing standardisation are used. Skill matrix charts are also used as well as flagging systems (i.e., auto fault register, Andon lights etc.). GEMBA (shopfloor innovation) is heavily “championed” (*Manager*) by technical services and practised by maintenance. However, although maintenance have “bought into” (*manager*) the visual management concept, it has only happened in recent years.

5S (CANDO) (Monden, 1994). 5S is well understood by everybody and is part of the company culture. The company emphasis of the 5S approach is also based on practical needs. For example, floorspace is an issue, so orderliness and cleanness are necessary.

Continuous improvement (CI) (Bicheno, 2000) is the ongoing summation of the lean activities used by the company. Maintenance personnel although led by technical services, practise the concept and encouragement of CI.

Kaizen activities (Imai, 1986). The maintenance function and technical services use Kaizen activities to re-emphasise their CI strategy and direction. A recent example of using Kaizen style workshops is monthly improvement meetings to eliminate wastes in maintenance (e.g., the experimental reduction of PM tasks and activities) and implement improvements.

Overall equipment effectiveness (OEE) (Nakajima, 1988). OEE was introduced to the company in 1996 / 1997. Its use has been patchy due to poor control, through management changes, staff shortages, and manufacturing system changes, etc.

Supplier associations. (Bicheno, 2000). The company initiated supplier associations in 1996 /1997 to improve spare parts delivery. Early initiatives proved successful but soon tailed off as a result of vendor “disinterest” (*Manager, technician*) and “support” (*Manager, technician*). This was redressed in 2000, whereby vendors and contractors were “obliged” (*Manager*) to improve delivery co-operation, design co-operation and training, or risk losing business.

Mapping (Hines *et al*, 1997) is used by maintenance and technical services, but only when production require planned resource logistics as a combined initiative.

B2.3 Additional recorded comments

In addition to providing evidence of lean activities within the company by maintenance and the technical department, some notable comments were recorded during formal questioning:

“Over recent years the company has experienced unprecedented demand for its product, gone through change of ownership, coped with skills shortages especially in maintenance, overcome production quality issues and improved manufacturing capacity with decreasing workspace availability. In turn, this has forced the maintenance function to evaluate its capability and contribution to the business in terms of accountability, quality of service and flexibility. Hence, the re-emphasis of previous lean practices and the introduction of newer lean techniques, among others. The formation of a technical services department, as a centre for innovation and driver for waste reduction and improvement, has allowed an understaffed maintenance function to focus more on its task requirements without losing touch with change. By taking this approach, maintenance feel that it is less likely that any beneficial changes introduced would fall to the wayside as a result of other issues. Overall, the introduction and use of lean techniques by maintenance have been generally accepted as useful tools to use. However, there is still a long way to go in terms of lean innovation and practice.”

(Head of department for technical services and maintenance).

B2.4 Observations

Visual checks of the maintenance function and production line were conducted over three visits. The use of 5S was evident throughout the plant and maintenance, as were production line-side spare part trays. Issues concerning lean procedures, activities, progress, responsibilities etc., were shown on storyboards (See Figure B1 for storyboard examples). The storyboards positioned throughout the factory, satellite maintenance areas and technical services provided up to date information on: quality, training, activity updates, top ten losses, skills matrixes, project outlines and action plans. Tooling shadow boards or visual machine-side record sets concerning TPM activities, responsibilities etc., were not noticeable.

During the observation period a manager provided documented examples of skills matrixes used by maintenance, NEPT and EEM and vendor feedback documentation, Current vendor / supplier association agreements with maintenance and technical services, energy management initiatives, project plans, improvement proposals, an overall maintenance business plan for 2001, and maintenance assessments.

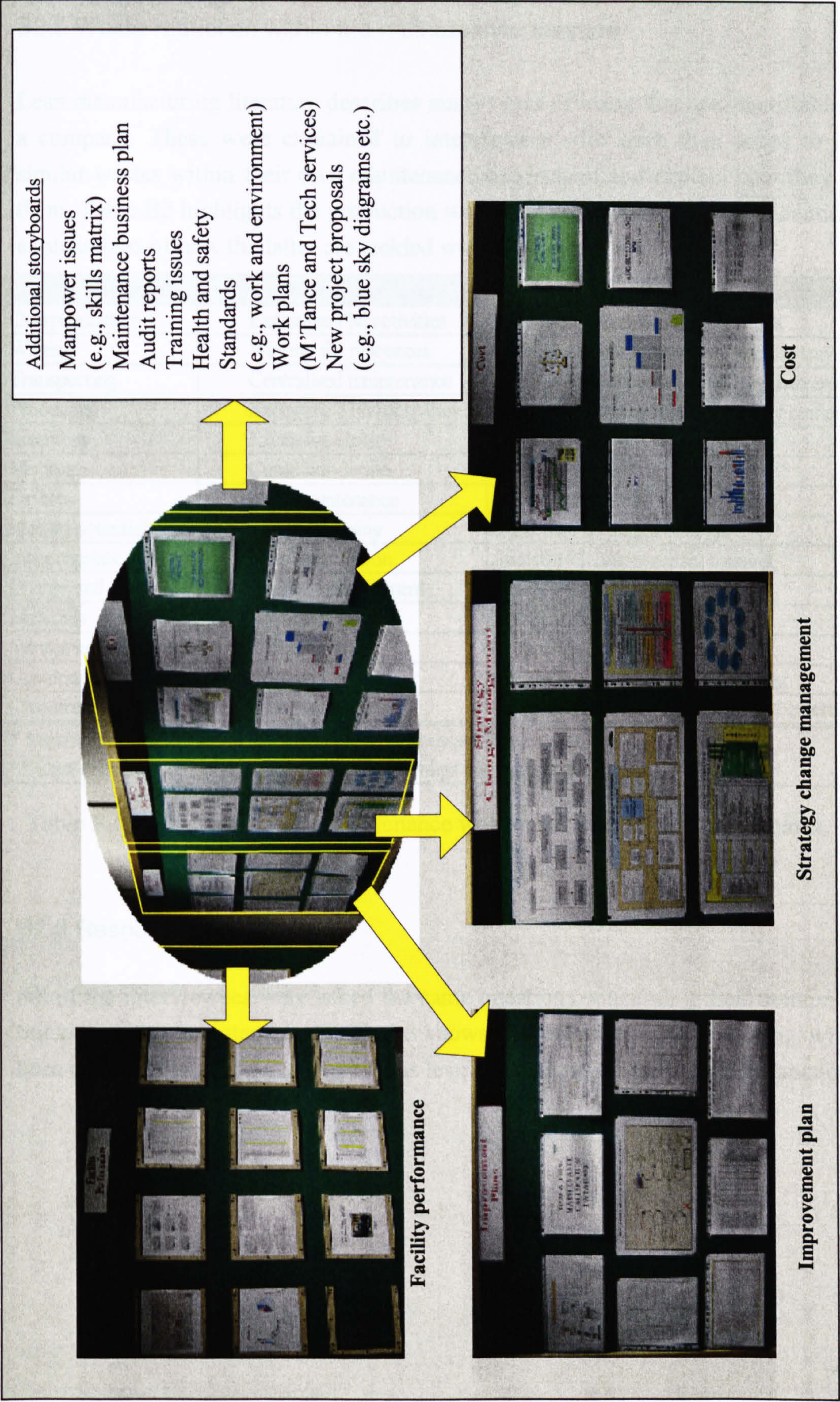


Figure B1 Storyboards for maintenance and technical services

B2.5 Waste reduction within the maintenance function

Lean manufacturing literature describes many types of waste that are identifiable within a company. These were explained to interviewees who were then asked to identify similar wastes within their own maintenance department and explain how they tackled them. Table B2 highlights the production wastes, the maintenance wastes identified and explanations of how the latter are tackled within the company.

Production wastes	Maintenance wastes	How maintenance wastes are tackled
Overproduction	Excessive PM activities	*Planned / scheduled PM activities
Waiting	Waiting for resources	Satellite workshops / stores, lineside trays etc.
Transporting	Centralised maintenance	Satallite workshops and lineside maintenance
Processing	Excessive TPM activities	Escalation capping, (i.e., capability guidelines)
Inventory	Excessive stock	FIFO spare parts
Motions	Could not define	Could not define
Defects	Poor maintenance	Skills matrix, EEM / NEPT teams
Human potential	Lack of training	Skills matrix, taught courses
Inappropriate systems	Poor information	Automated fault systems, training
Energy and water	Energy management	**ISO 14001
Materials	Poor re-design	NEPT / EEM teams
Service and office	Office wastes	Recycling
Customer time	Poor procedures	Standards / Storyboarding Training
Customer defection	Poor maintenance	Skills matrix, Training internal and external
* Improvement meetings i.e., assessment of unnecessary PM activities		
** Cost effective comparisons for operational savings and energy tax breaks		

Table B2 Production wastes, maintenance wastes and tackling the maintenance wastes

B2.6 Response to questions

All of the interviewees were asked the same questions concerning their opinion of lean thinking within maintenance. Table B3 shows the response to the question, “what have been the benefits of introducing various lean concepts to the maintenance function?”

Head of department	Manager 1	Manager 2	Maintenance technicians x 3
Increased workforce responsibility-ownership	Clearer task definition	Problem solving techniques	Less firefighting
Better skill integration	Shared responsibility	Greater task flexibility	Less skill demarcation
Increased throughput	Waste reduction	Task ingenuity-innovation	Better communication
A more robust maintenance function	Improved maintenance quality and service	Better facilities	Quicker breakdown response
Standardising of procedures / activities	Improved management, team and production communication	Less firefighting	Access to training-information

Table B3 Response to question: “What have been the benefits of introducing various lean concepts to the maintenance function?”

Table B4 shows the responses from the question “Has there been a downside to the lean concepts used within the maintenance function?”

Head of department
<p>“Initially yes: The unwillingness of some to share their maintenance knowledge with production, and to accept lean practices in the early years resulted in a high turnover of maintenance staff. In retrospect, this was a good thing as it allowed us to learn from the mistakes and rebuild.</p> <p>Difficulties have occurred in translating essentially business and production led lean techniques to suit the maintenance function, but this is being addressed by the combined efforts of the maintenance and technical service function.</p> <p>Overall, there has been a pragmatic acceptance of the lean techniques used. So if you exclude the early years, there has been no real downside to using lean techniques within maintenance.”</p>
Manager 1
<p>“There were various activities and practices implemented, especially in the beginning, that were not really successful in terms of acceptance, workability or just died out through lack of support. In fairness however, trying to achieve too much, too quickly, in too many areas contributed to the lack of success of the original aim.”</p>
Manager 2
<p>“If you take away the earlier lack of success, then overall, the use of lean within maintenance has been no bad thing, despite the shortage of required on roll manpower. However, if a change of approach had not been taken, then the lack of success may have continued.”</p>
*Maintenance technicians (x3)
<p>“Previous lean initiative roll-outs asked too much, too soon, in too wide an area, making it difficult for some to cope with the change. Spreading the load or re-emphasising previously used lean techniques, and introducing newer practices more rationally, eased the demand and allowed us to focus more on the overall objectives, without compromising our day to day jobs. In this respect, apparent downsides of using lean within maintenance have been hardly noticeable, but a lot more can be done in terms of getting lean practices to work better.”</p> <p>* This is a combined summary of three maintenance engineers responses to the same question.</p>

Table B4. Response to question: “Has there been a downside to the lean concepts used within the maintenance function?”

Interviewees were asked their opinion on the continued use of lean concepts within their maintenance department and how they viewed the future growth. Table B5 shows the responses from this question.

*Head of department
<p>“Build upon and expand the lean practices already in place, and introduce greater decision making autonomy, i.e., change / idea start-ups etc throughout. To get production to buy into maintenance, starting with the planned revised approach to OEE practice. Promote greater business awareness and contribution within maintenance at all levels. Develop greater worker ownership of facilities, including all none critical maintenance and improvement strategies, enabled by the facilitation of the combined maintenance and technical service function.”</p> <p><i>* Documented information, (not for the public domain) was given to this researcher outlining the key areas of achievement and focus for maintenance.</i></p>
Manager 1
<p>“Build on the earlier successes of EEM and NEPT activities. Develop greater involvement at all levels in all areas, concerning new equipment design or redesign for improved production facilities.”</p>
Manager 2
<p>“Develop more effective use of technology and resources, that not only assist the maintenance function but aspects of production as well. Work on greater interaction between production and maintenance, to reduce the various types of dependency one has upon the other.”</p>
*Maintenance technicians (x3)
<p>“Greater personal development and responsibility. Access to further training, in particular business awareness and management. Be seen more as facilitators of improvement and efficiency change throughout production. As processes improve and automation becomes more common, our professional skills will focus more on high-tech solutions, whereas line-side operators will take ownership of lower level non-critical maintenance and improvements.”</p> <p><i>* This is a combined summary of three maintenance engineers responses to the same question</i></p>

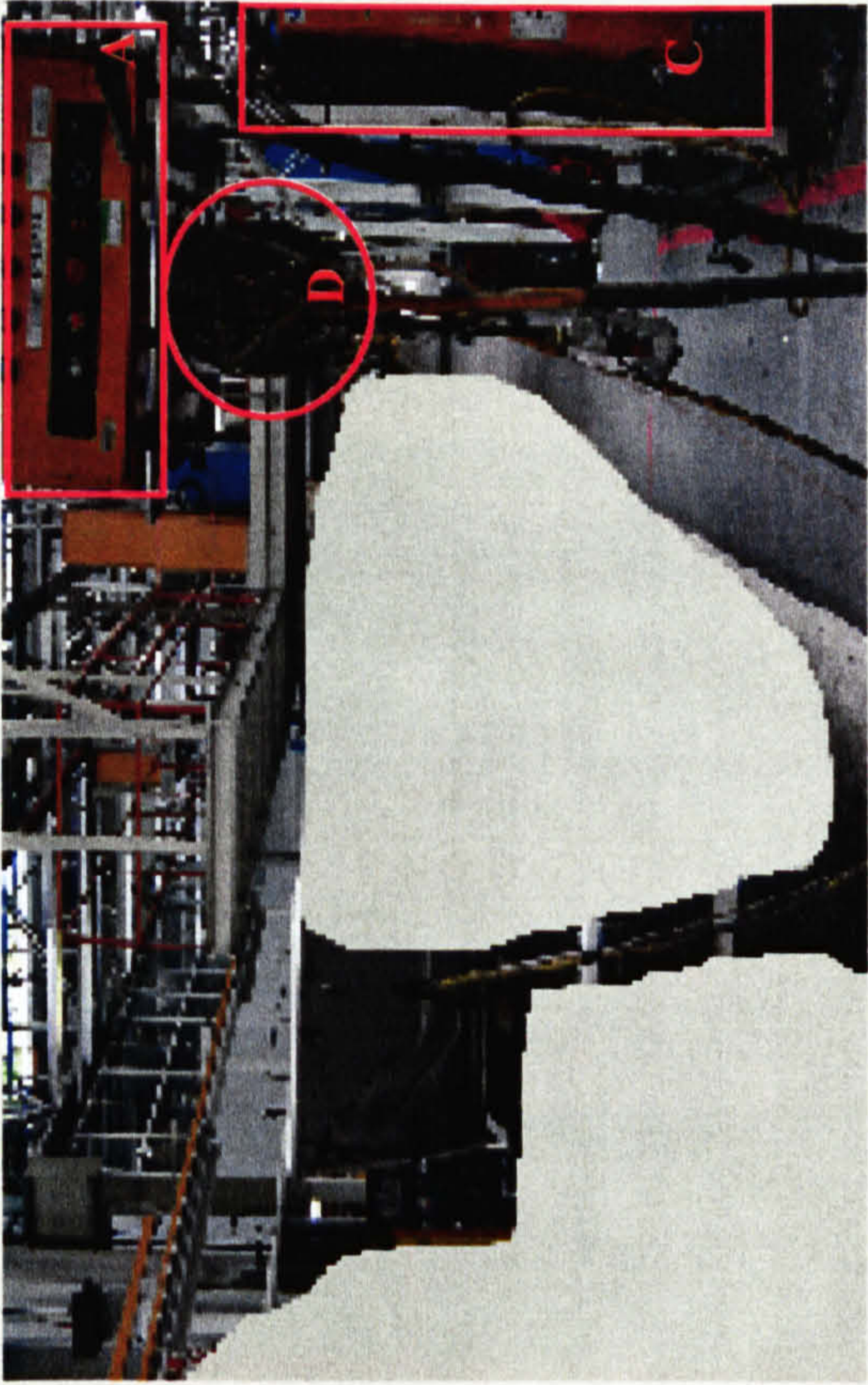
Table B5 The future of lean practices within maintenance?

B2.1.5 Additional information provided

Maintenance and technical services also provided additional information to highlight their use of lean thinking in improvement projects. Figures B2 and B3 provide an example of a project highlighting pre and post improvement changes within the fluid-fill area of an assembly line. Characteristics of lean used to add value within the fluid-fill area in relation to those identified in Table B1 are discussed here.

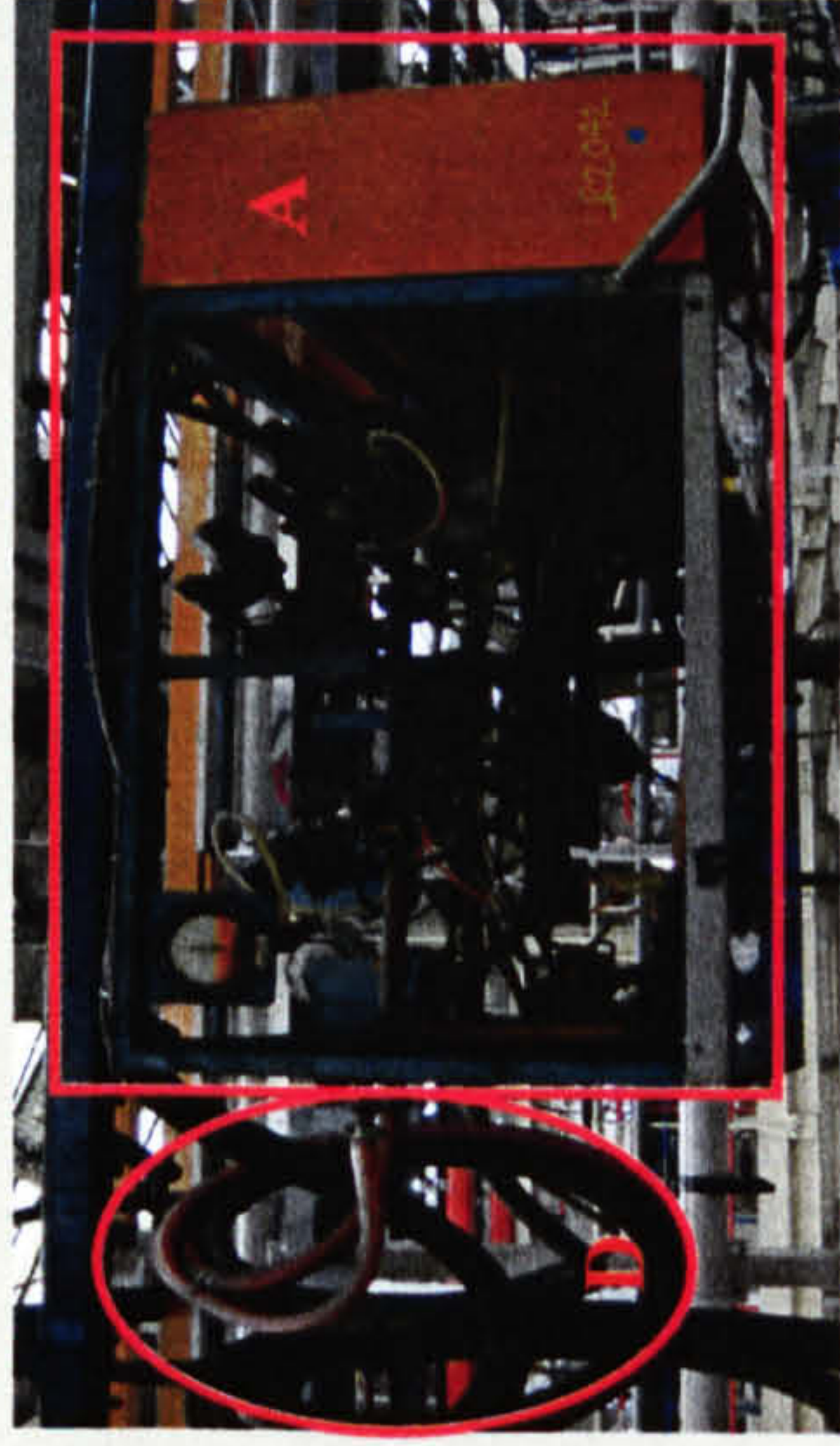
Identification for improvement within the fluid-fill area of the assembly line was through the use of 5S and visual management. The improvement project was more thoroughly investigated using Kaizen, root cause problem solving and mistake proofing (i.e., Pokayoke) techniques. Storyboards were used to clarify the aim of the project, activities involved and tools required. These included technical feasibility issues, logistical, financial and investment considerations. To standardise the improvement project maintenance and technical services (in partnership with production) made use of process and resource activity mapping. Root cause problem solving and Pokayoke also helped form appropriate new equipment purchasing and early equipment management teams (NEPT, EEM) for the project. Supplier associations with technical services enabled flexibility to be built into the project design and help with budget efficiency.

The expected benefits of the improvement project within the fluid-fill area of assembly were greater area reliability, operator efficiency, maintenance access, waste reduction in terms of time (maintenance, operator checks), materials (spare parts availability and logistics, fluid storage etc.), Process (combined fill and test), ergonomic design consideration, reduced service costs, and process visibility for better integration of maintenance and operator based maintenance checks.



● Layout problems

- Control panels above head height (A)
- Additional gantry level control equipment (B)
- Lineside storage and equipment (C)
- Feedline (D)



● Activity problems

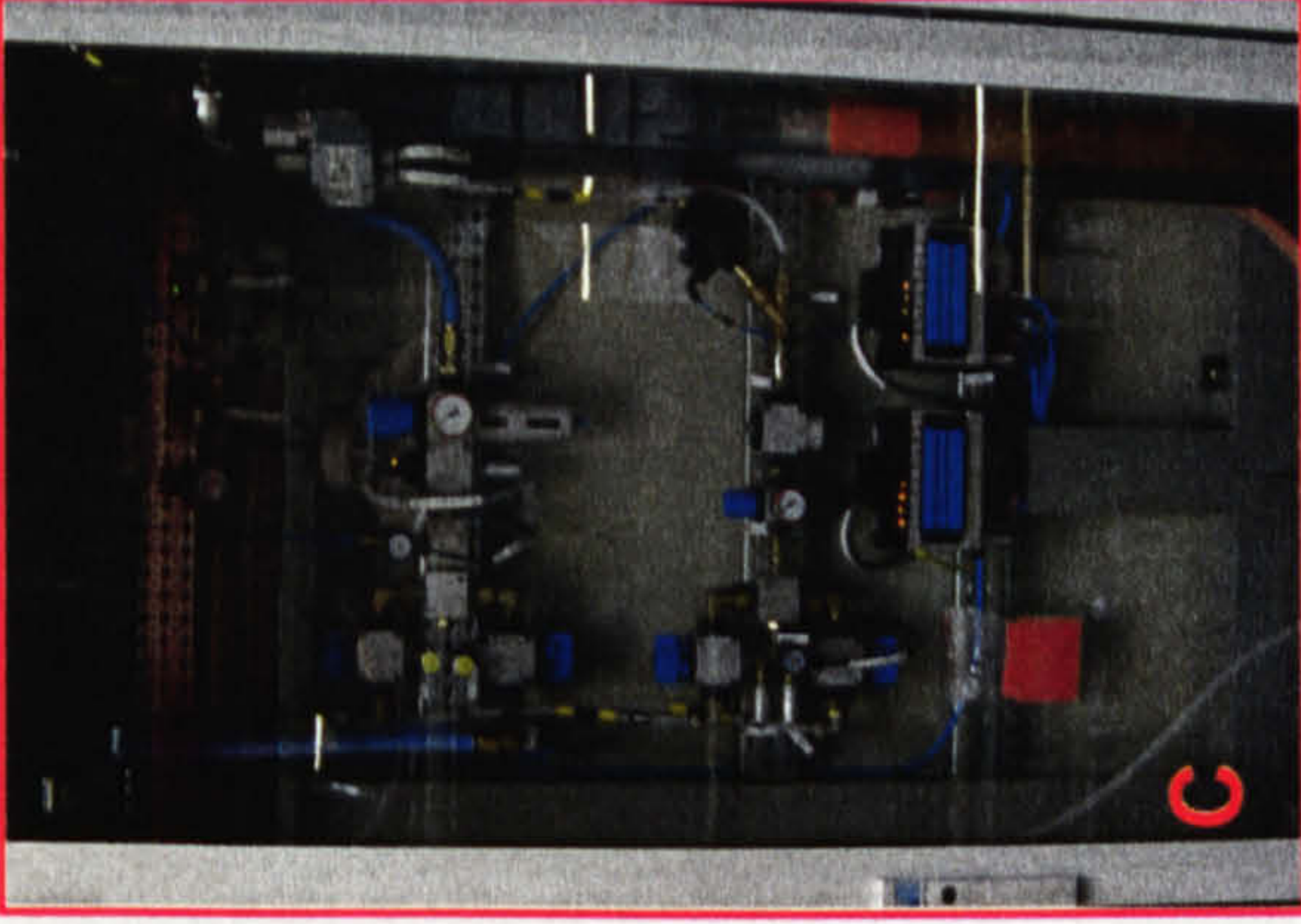
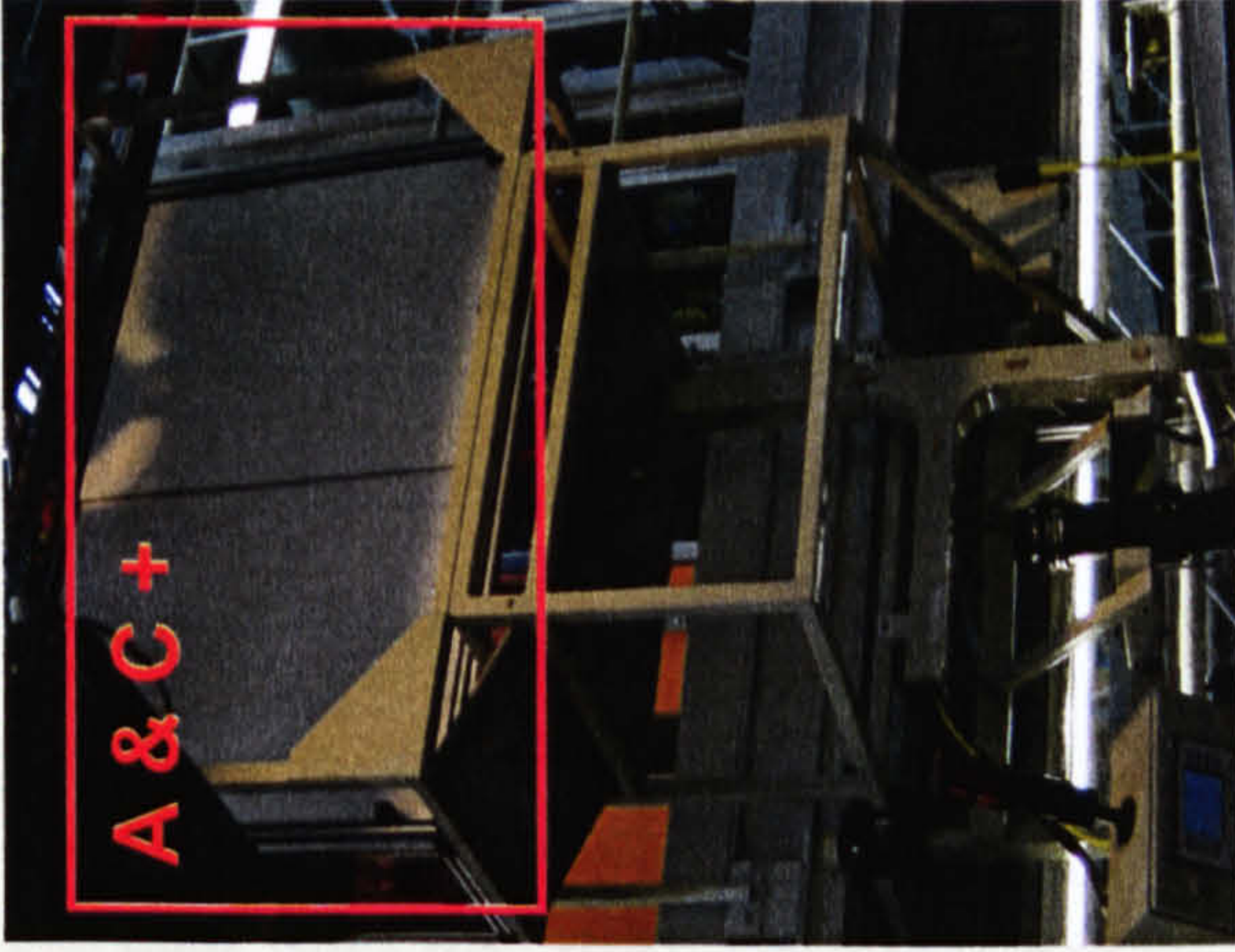
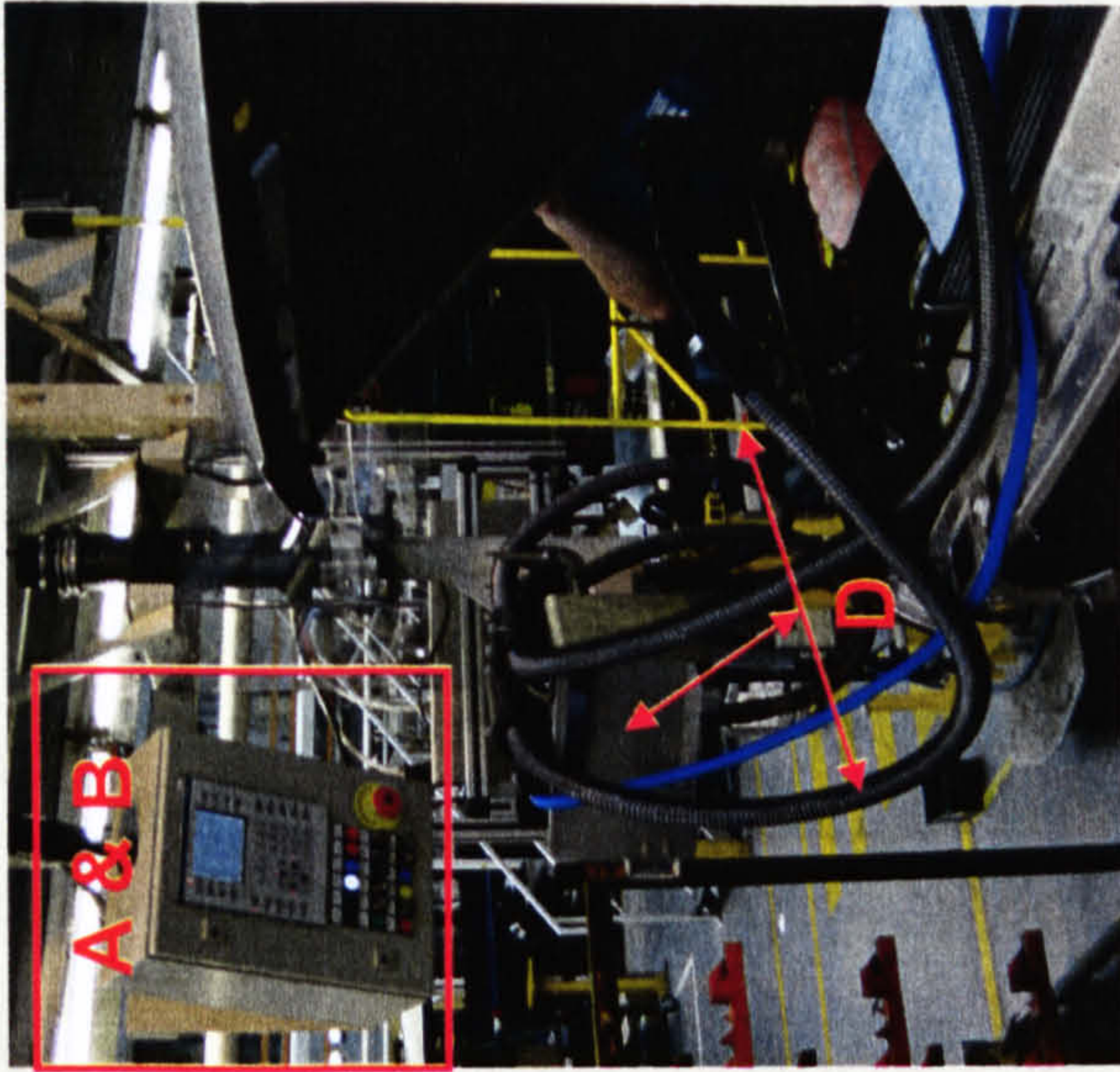
- Operator intensive activity
- Production logistics
- Poor maintenance access
- High maintenance hours
- Accessibility
- Spare parts availability

● Identification and feasibility

- Visual management / 5S / Kaizen
- Project design / scope
- Financial justification
- Elec. / Mech. / Control feasibility
- Ergonomic considerations
- Competitive tendering

Operation information, pre-improvement: During assembly cars are filled with brake fluid. An operator drags a feedline from a fixed position to the car, fits the pipe to the brake fluid container. When the container is full the operator unclips the feedline returns it to its original position ready for the next car. If for any reason the fluid-fill equipment is down, cars are filled manually then tested at the end of the assembly run, or pushed back to the assembly start to be filled and tested, but only if the equipment is in working order

Figure B2 The use of lean in an improvement project, pre-improvement fluid fill area



● Involvement

- Technical services
- Maintenance
- Production
- Machine vendors
- Suppliers
- NEPT / EEM teams

● Changes

- Automated carriageway
- Swing mounted feedline
- Accessible control
- Transparent panels
- Visual checks / control

● Benefits of improvement

- Increased reliability
- Operator efficiency
- Ease of operation
- Less waste (time / process etc)
- Reduced service cost
- Spare part availability
- Maintenance / process visibility

Operation information post-improvement: During assembly combined brake fluid-fill and testing are undertaken. An operator sets a swing mounted (integrated with automated carriageway) feedline to a car. Progress condition is displayed on a monitor. At the end of each cycle the operator releases the feedline and the system returns to its original start position for the next car

Figure B3 The use of lean in an improvement project, post-improvement fluid fill area

B3 Measuring the performance of the maintenance function

B3.1 Company measures for maintenance

The company does not directly measure the overall performance of the maintenance function. A basic measure for maintenance performance is throughput, i.e., has the volume of cars manufactured increased or decreased? If the volume has decreased, what are the reasons?

The company, as part of a global organisation, is in the process of implementing a unified Intranet based system to record certain aspects of their maintenance function, in line with other companies within the organisation. Previously an MMIS was used to manage information.

B3.2 Conditions of measurement

Metrics involving cost data was not available, so could not be used. Data post July 2001, and prior to January 1998 was not available.

B3.3 Measurement period and focus

Of the manufacturing assembly plants under investigation, quantitative maintenance data from the MMIS was obtained from one site only. The period of data collection extended from January 1998 to July 2001 (43 months).

A maintenance manager and technician were interviewed prior to collecting the data concerning major events during the measurement period that they felt might affect the accuracy of the data collected. Table B6 highlights the issues discussed and what effects they had on the maintenance function during the period of collection. Short periods of disruption (i.e., industrial action, new model introduction etc.) were considered by the interviewees not to be of significant importance to note. After the data was analysed further answers were sought of the interviewees to explain periods of disruption not previously discussed. Additional information provided by the interviewees stated that there has been a long-term shortfall of 10 engineers “required on roll” (*Manager*) within the site under investigation.

Major issues affecting maintenance during period of data collection		
Month(s)	Event	Impact on maintenance
11-15	Installation of primary equipment during month 10	Increase in breakdown repair hours, decrease in PM activities
21-24	Increase in accessory lineside equipment alterations for “production ramp-up” in month 28 and model change introduction in month 31	Increase in breakdown repair hours during trial runs and tests
25-27	Continued preparation for “production ramp-up” in month 28 and model change introduction in month 31	High number of unscheduled tasks resulting from trial runs and tests from months 21-24

Table B6 Issues affecting maintenance during measurement period

B3.4 Performance indicators used

Based on three criteria: ease of data retrieval, cost of retrieval and ease of understanding the results, a spreadsheet application was used to calculate an output for the performance indicators used for this investigation.

Table B7 summarises the appropriate performance indicators chosen for this investigation, based on the lean techniques used and availability of data from the MMIS used by maintenance.

The indicators presented in Table B6 are used to indicate the impact of using the lean concepts presented in Table B1, and the subsequent impact they may have upon the maintenance function. However, for this research, only six of the fourteen techniques presented in Table B1 could be investigated. These are TPM/ FTPM, continuous improvement, OEE, Standards, Pokayoke and root cause problem solving.

Performance indicator	Indicator calculation	Desired outcome
Breakdown repair hours	$\frac{\text{No. hours spent on breakdowns}}{\text{Total direct maintenance hours}}$	Trend decrease
Evaluation of PM and Predictive maintenance	$\frac{\text{Predictive and PM insp. completed}}{\text{Predictive and PM insp. scheduled}}$	Trend increase to unity
Manpower efficiency	$\frac{\text{Hours worked as scheduled}}{\text{Total hours worked}}$	Trend increase to unity
Equipment availability	$\frac{\text{Equipment runtime}}{\text{Equipment runtime} + \text{B/Down time}}$	Trend increase to unity
Maintenance hours applied	$\frac{\text{Total maintenance hours}}{\text{Total production hours same period}}$	Once established ratio should tend to decrease or stabilise
Length of running	$\frac{\text{Tot Prod. output in units or hrs}}{\text{Qty repairs for same period}}$	Value increase
Unscheduled tasks	$\frac{\text{Man-hrs unscheduled jobs}}{\text{Total maintenance hours}}$	Trend decrease

Table B7 Maintenance performance indicators used for this investigation

B4 Output results

Based on the available information provided by maintenance, Figures B4-B10 represent the values of the performance indicators shown in Table B7 for the full 43-month measurement period. A trendline is used to visually highlight change over the 43-month period. For the maintenance function within this company, emergency events were classified with other unscheduled events, such as line stoppage. All emergency tasks were categorised as breakdown tasks or repairs.

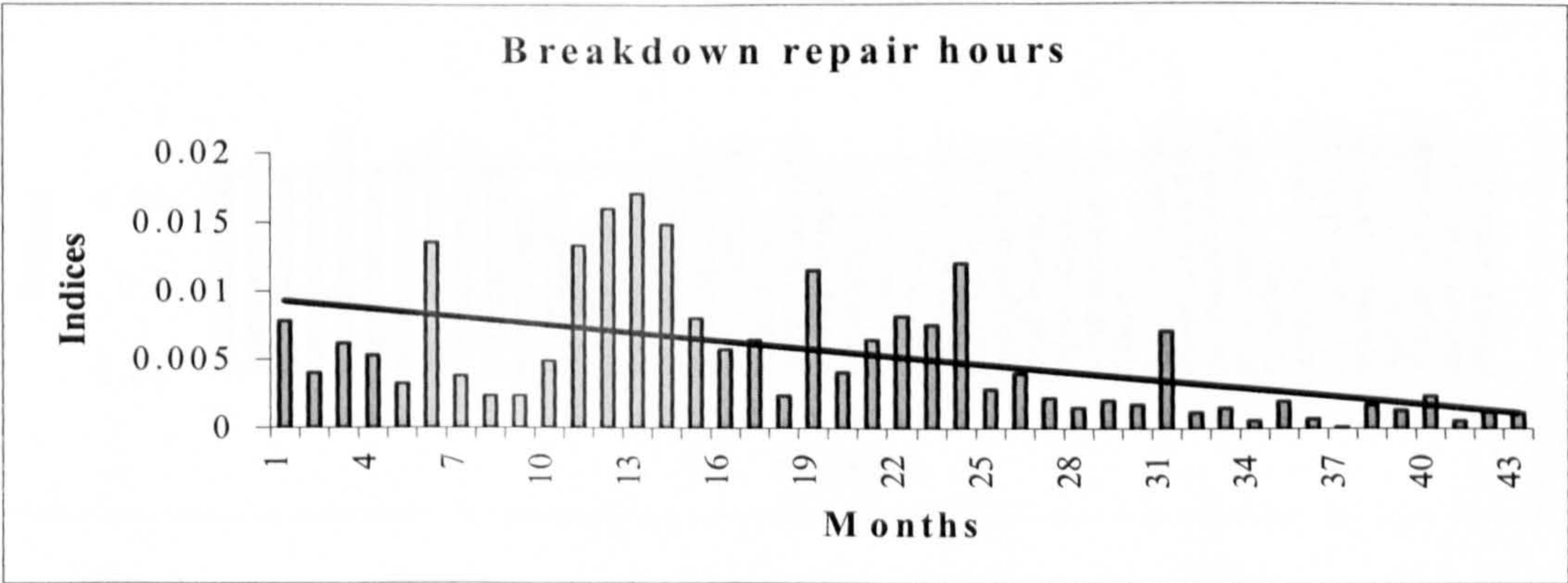


Figure B4 Breakdown repair hours

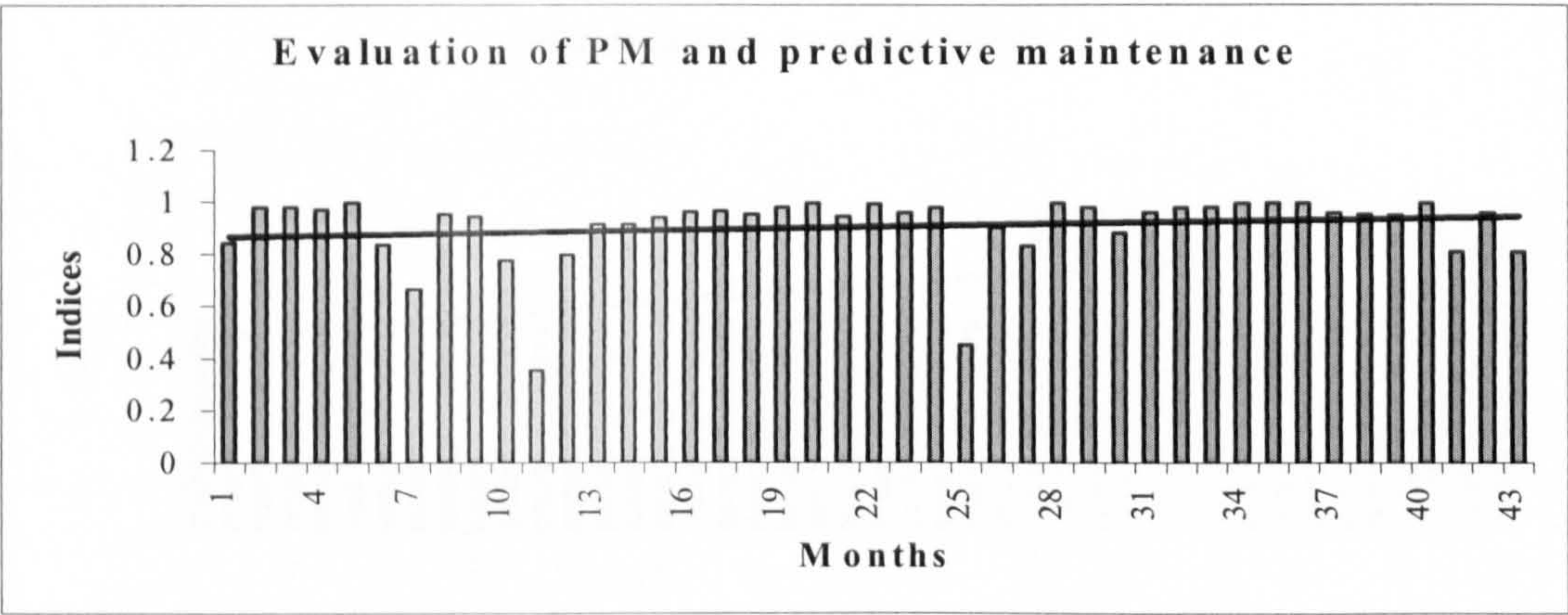


Figure B5 Evaluation PM and predictive maintenance

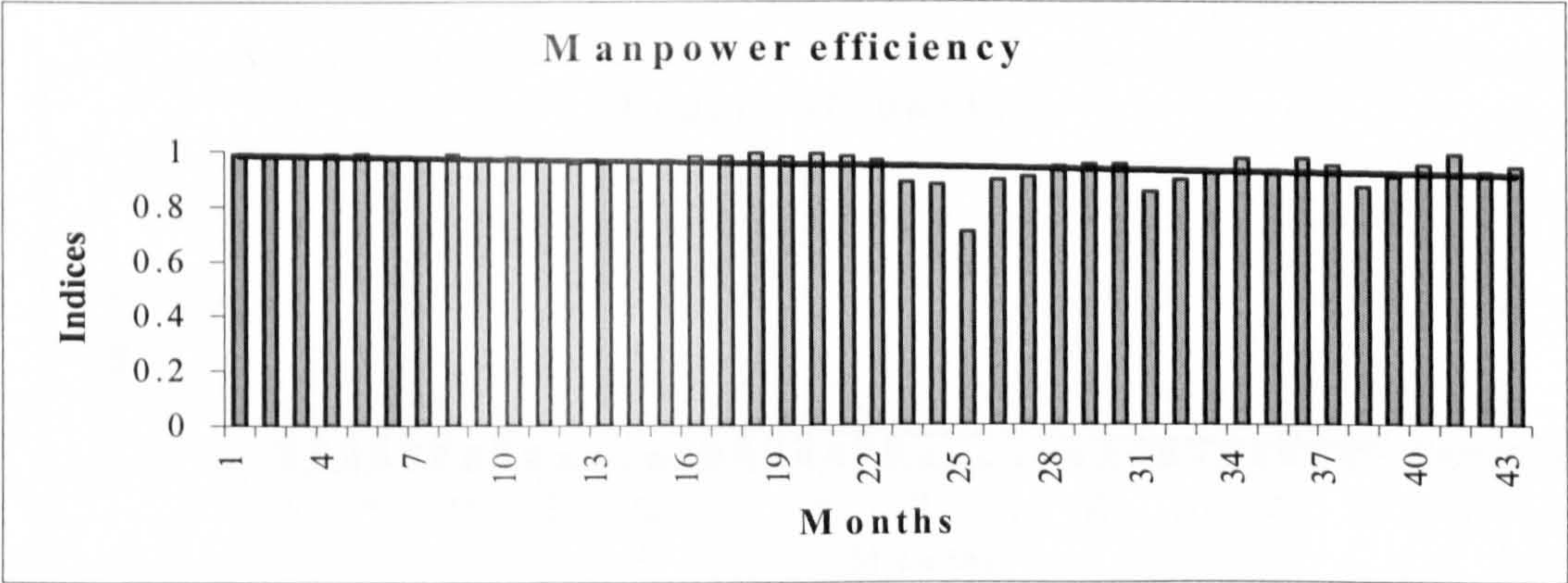


Figure B6 Manpower efficiency

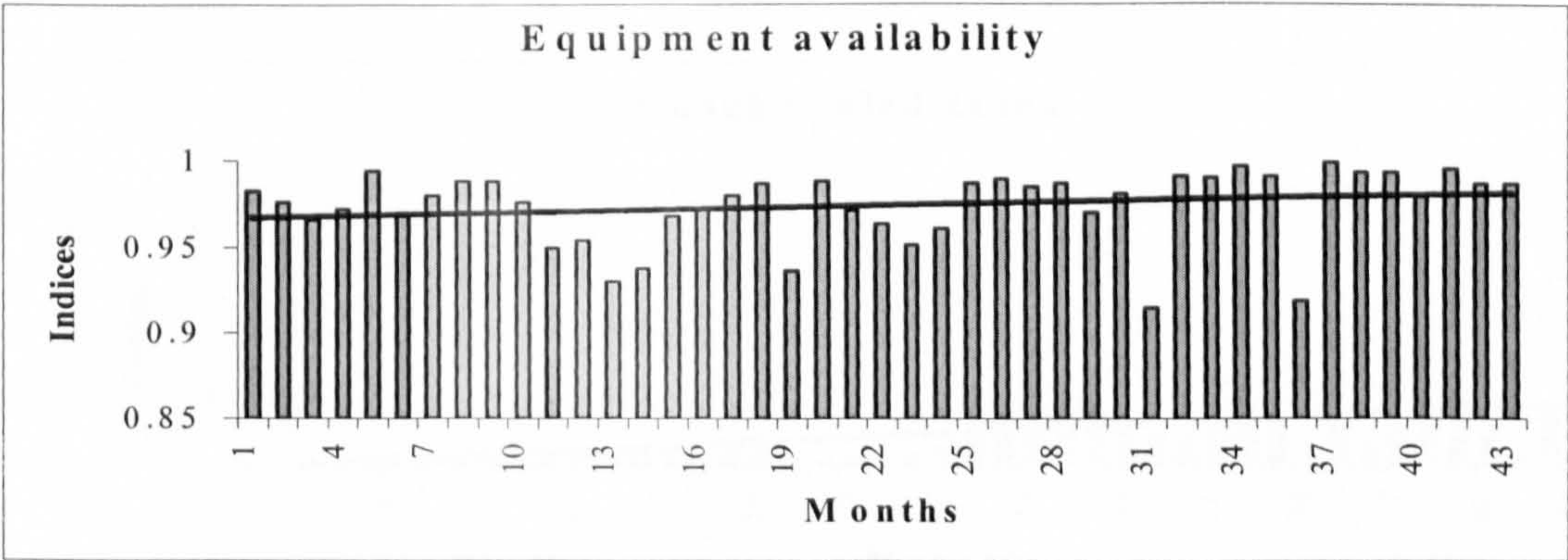


Figure B7 Equipment availability

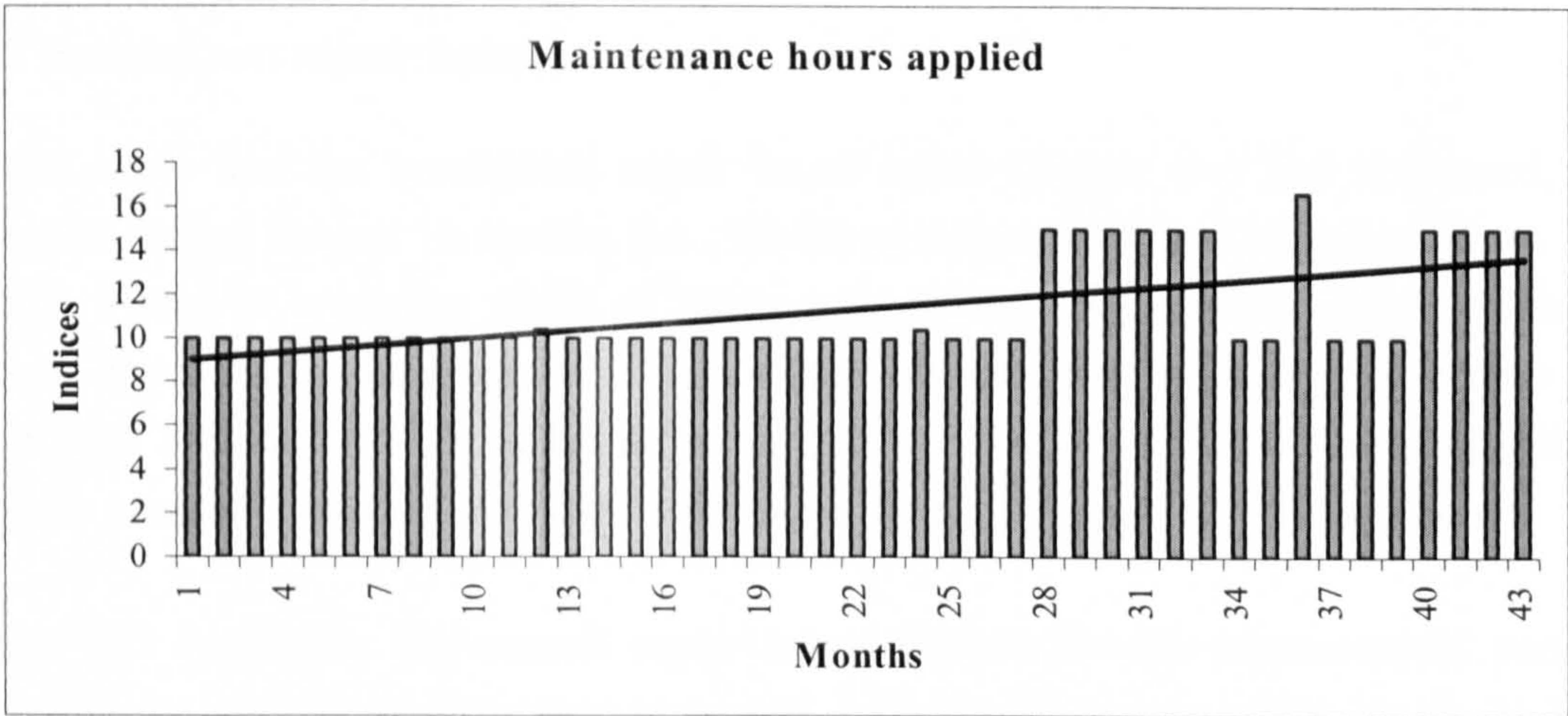


Figure B8 Maintenance hours applied

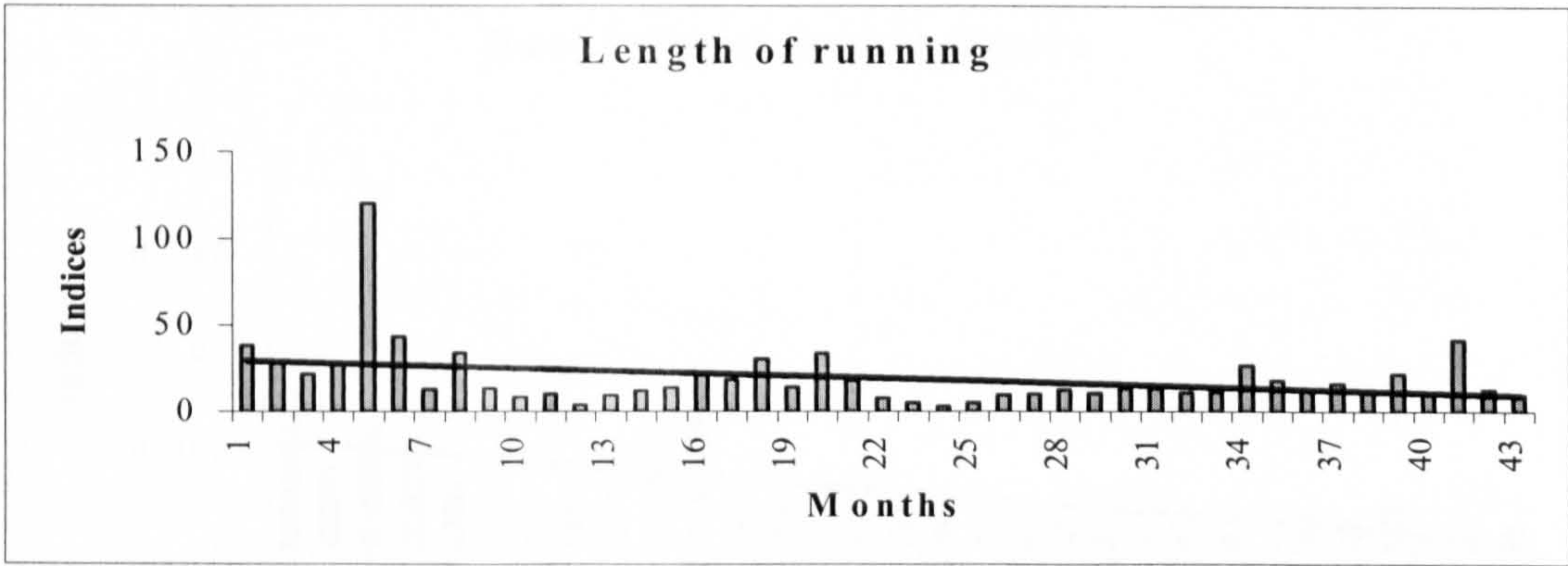


Figure B9 Length of running

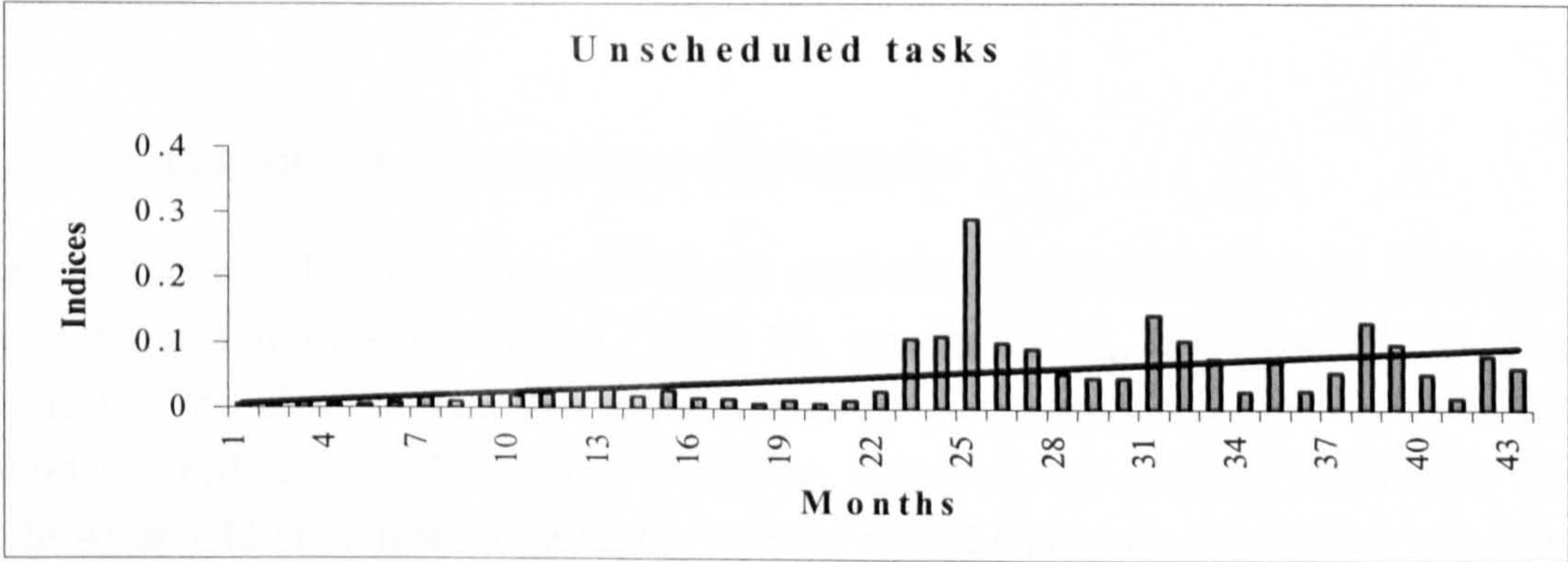


Figure B10 Unscheduled tasks

B5 Summary of post investigation of data analysis and results

B5.1 Breakdown repair hours

Results show that the breakdown repair hours index (Figure B4) had decreased, in particular during the last 16 months (i.e., 28-43) of data recording. The index surges for months 6 and 19 were the result of hours worked well beyond line stoppage time. “Hours beyond line stoppage time is usually due to poor maintenance access to equipment” (*Manager*). The index surge for month 31 coincided with the introduction of a new model for assembly, compounded by a shutdown period within that month.

Figure B11 highlights the overall repair hours indices for the measurement period excluding the periods of disruption presented in Table B6 (e.g., months 11-15, 21-24) and those highlighted post analysis through interview (e.g., months, 6, 19 and 31).

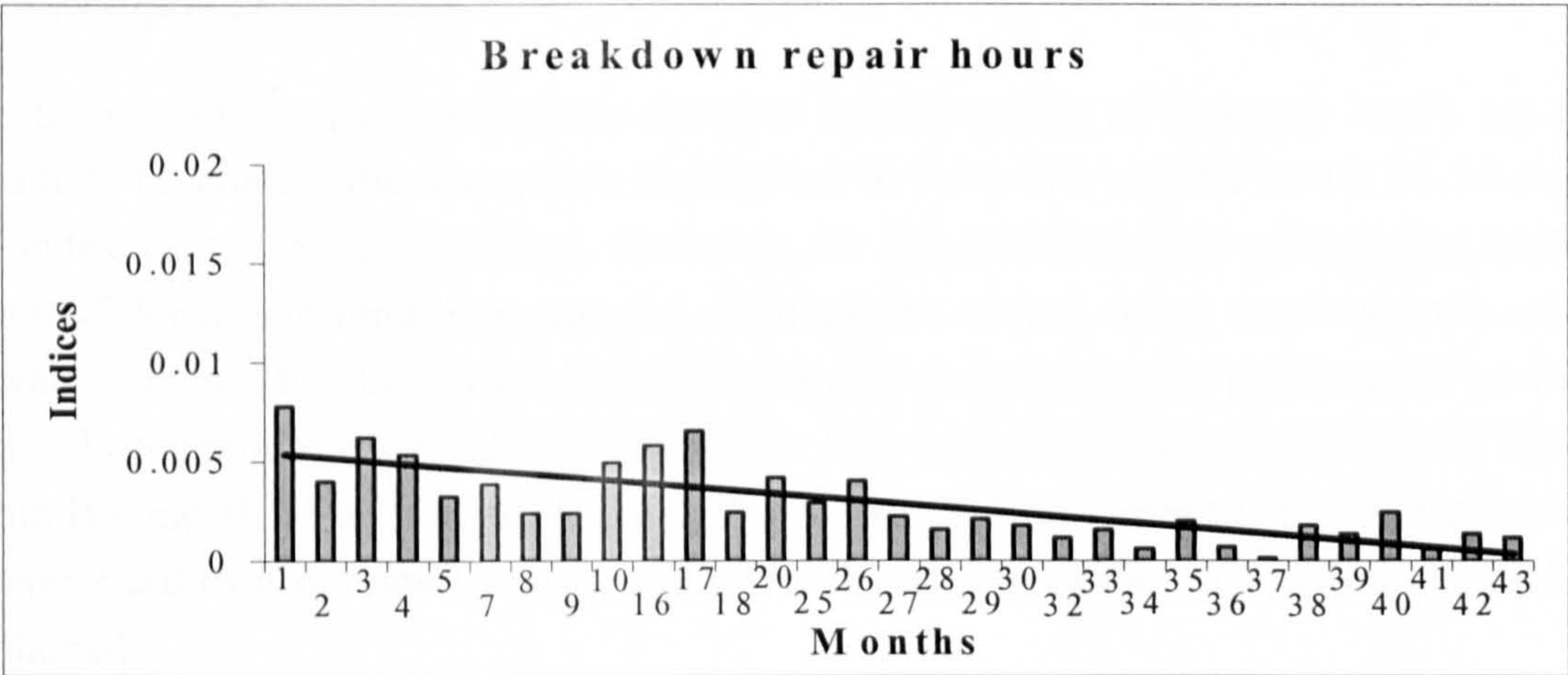


Figure B11 Revised breakdown repair hours

B5.2 Evaluation of PM and predictive maintenance

Figure B12 shows the evaluation of PM and predictive maintenance indices excluding the periods of noted disruption (e.g., Table B6, months 11-15, 21-24 and 25-27). The analysis of data also showed that from month 37 (i.e., Jan 2001) the experimental reduction of PM tasks and activities increased. However, the reduced index ratio for months 41 and 43 are a result of a higher number of PM tasks to be completed at a later date, than inclusion of cancelled PM tasks for those months.

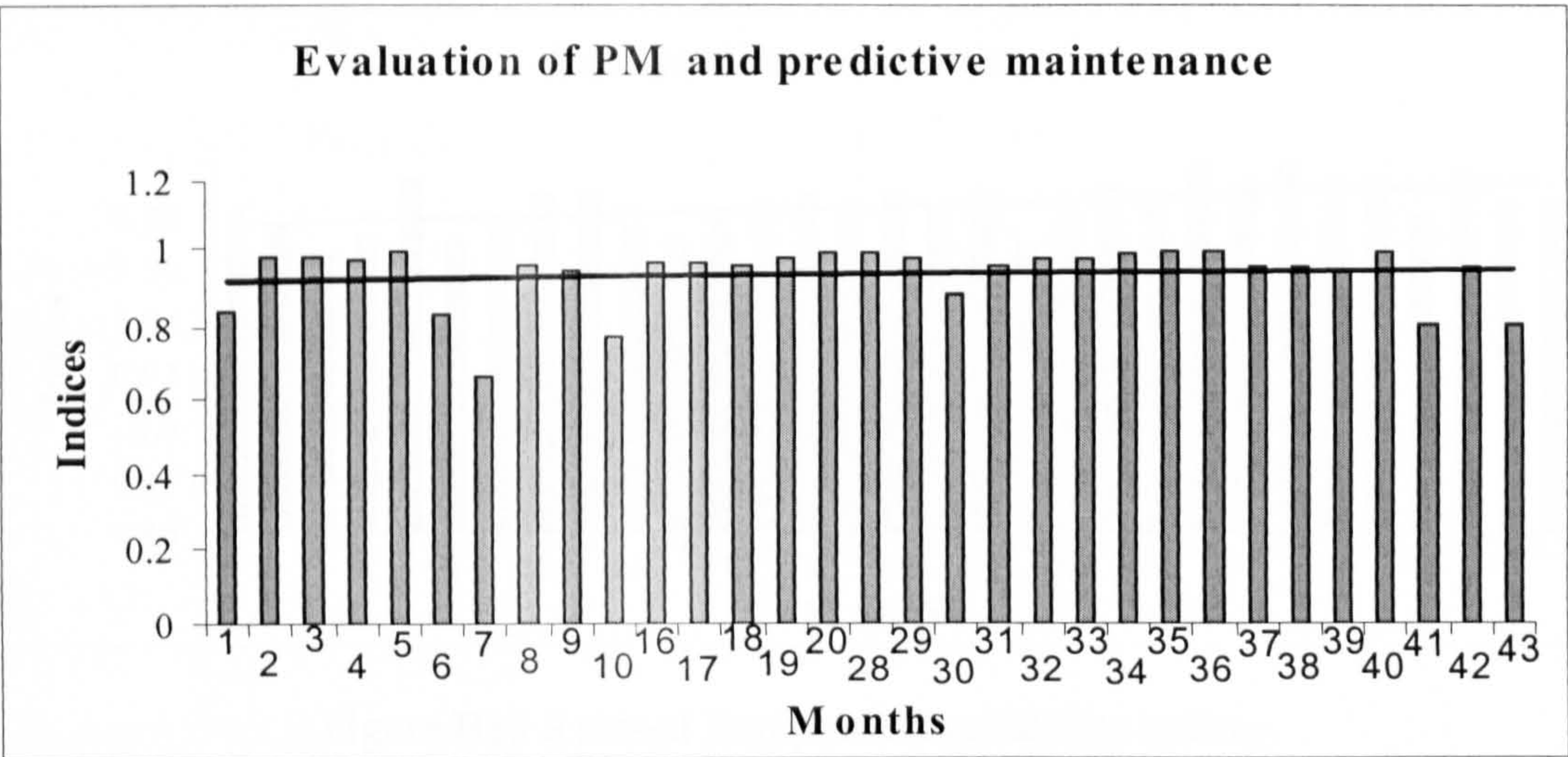


Figure B12 Revised evaluation of PM and predictive maintenance indices

B5.3 Manpower efficiency

The transfer of company ownership occurred around month 25 (January 2000). Up to month 25 (excluding the disruptions highlighted in Table B6, months 11-15, 21-24 etc.) the index value overall decreased. However, for this period the lowest recorded index was 0.97 for month nine. Post transfer, although the overall index was lower the ratio overall increased for this period. The highest index recorded for the post transfer period was 0.98 for month 41. Excluded months for this period included months 25-27 from Table B6, month 31 as it coincided with the introduction of a new model for assembly, compounded by a shutdown period within that month, and month 38 which could not be explained.

B5.4 Equipment availability

Overall the equipment availability index (Figure B6) showed improvement. A sudden drop in the availability value for month 19 was a result of increased breakdown time for that month. Similarly, the low value of 0.91 for month 31 coincided with the introduction of a new model for assembly. However, a similar value for month 36 could not be explained. Figure B13 highlights a revised representation of the equipment availability indices omitting the periods of noted disruption from Table B6 (e.g., months 11-15, 21-24) and months 19, 31 and 36 highlighted during post analysis questioning.

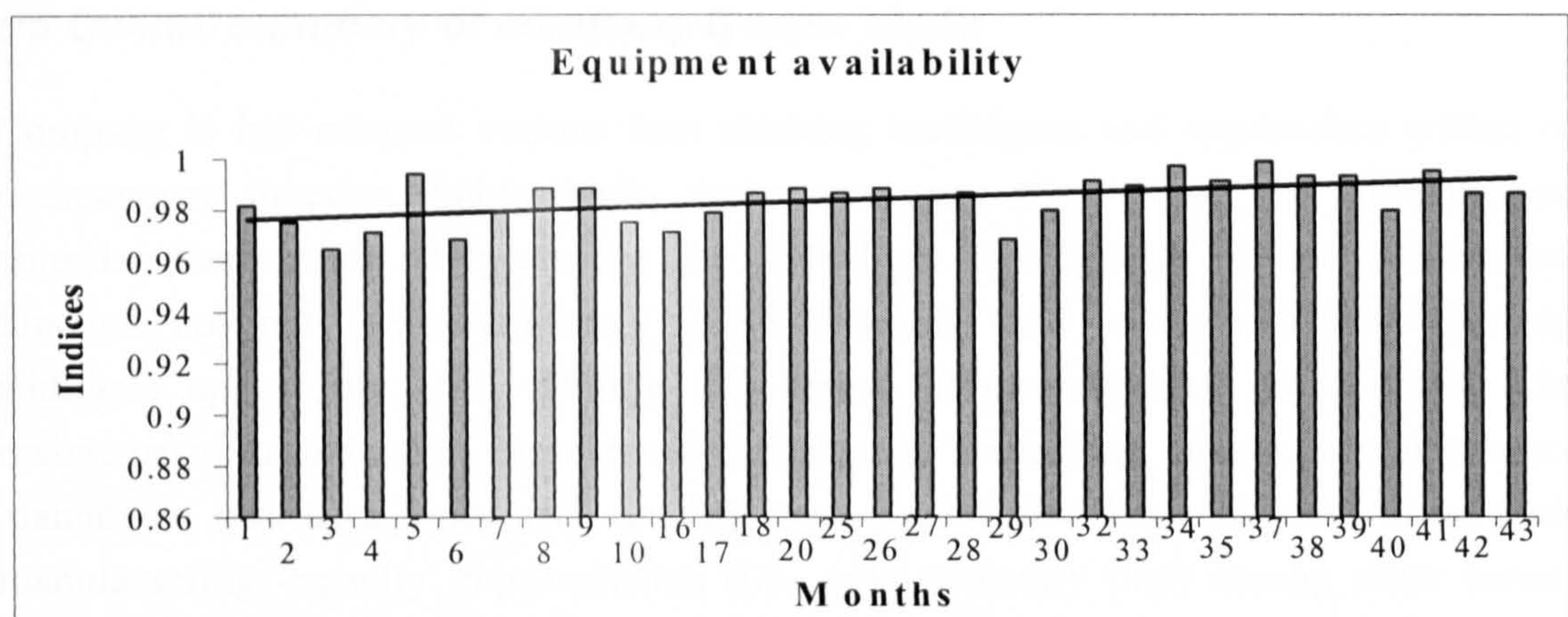


Figure B13 Revised Equipment availability indices

B5.5 Maintenance hours applied

The maintenance hours applied index (Figure B7) remained stable until a change in production shift hours in months 28-33, 36, and 40-43. During like periods the index was also stable.

B5.6 Length of running index

Overall, the length of running index (Figure B8) pre-ownership transfer (i.e., before month 25) decreased. The high index value for month 5 during the first period was due to the very low number of repairs recorded for that month. Excluding the low number of repairs recorded for months 34 and 42 post transfer, the length of running index value increased overall.

B5.7 Unscheduled tasks index

Prior to ownership transfer in month 25 and accounting for the elimination of the periods of disruption shown in Table B6 the unscheduled tasks index (Figure 9) increased. During the post-transfer period, taking into account the periods of disruption highlighted in Table B6 the index decreased overall. The index surge for month 31 coincided with the introduction of a new model for assembly. A similar increase in month 38 could not be explained.

B6 Overall summary of company B case study

Company B has adopted various lean thinking techniques and approaches within its maintenance function. Subjectively, the users accept the role of lean thinking and consider them useful. Objectively, the period of investigation of the maintenance function covered the re-emphasis (1998 onwards) and subsequent lean thinking additions up to July 2001. During this period of investigation, the company and maintenance in particular, experienced a change of ownership, continued maintenance manpower shortages, increased quality and production demands, and large-scale manufacturing capacity improvements (i.e., new assembly line) among other issues. Therefore, it appears that for the period under investigation, the use of lean thinking within the maintenance function helped improve or maintain their effectiveness in all practically measurable areas of performance.

Appendix C

Mail shot request to UK companies to assist in case study investigation of the maintenance function

C1 Introduction

Appendix C provides an example of the request letter and research outline sent to companies to seek case study research.

C2 Letter of introduction and additional information

School of Industrial and Manufacturing Science

Cranfield
University

Chris Davies
Freepost
SIMS Bldg 30
Cranfield University
Bedfordshire, MK43 0AL

Dear Sir,

I am a Ph.D. researcher within the Manufacturing Systems Department at Cranfield University.

The aim of my research is to improve the effectiveness of the maintenance function by applying good practices that I have identified from research into manufacturing.

The focus of my work has been to measure maintenance performance and I have developed a set of measures that I need to validate. To do this, I need to gather data from several companies. Would it be possible for me to visit you to describe my work and collect data to validate my theories?

I have enclosed a brief description of my research with a reply slip and freepost envelope and I look forward to meeting you in the near future.

Yours sincerely,

Chris Davies

Additional information

Research to date:

My research focuses on the use of lean thinking concepts within an organisation and their impact upon the effectiveness of the maintenance domain. More specifically, how lean thinking improves the maintenance function?

A lean thinking reference framework has been developed that reflects the lean thinking concepts possible within a company and maintenance in particular. For this reason a methodology to measure the impact of using such concepts upon and within the maintenance were developed. The set of measures are also required to measure maintenance generally regardless of the presence of lean thinking or not.

Measuring maintenance:

Performance measures are used to illustrate the position, progress and effectiveness of the maintenance function and should, if possible reflect all the relevant consequences. These have been shown to be problematic in terms of acceptance (i.e., too costly and time consuming) and interpretation (i.e., too complex). My research has overcome these issues by developing a set of performance indicators that may be used to measure the effectiveness of the maintenance function. This was done by assessing various approaches to manufacturing and the impact they have on the maintenance and then choosing the right performance measure to do the job.

Investigation approach:

The figure below highlights the three-stage approach I would like to undertake to measure maintenance performance. The first stage would involve a cross-reference tick list through a yes or no question and answer session. The second stage would involve taking measurements during a brief period of time and seeking opinion on the type of production and maintenance practices used. This stage can be conducted by survey and interview as well as recorded information. The final stage will consist of a feedback report highlighting my findings for your consideration.

STAGE ONE	STAGE TWO	STAGE THREE
Identify the processes that affect the maintenance function. Compare with lean reference framework	Measure the impact various activities have upon the maintenance function using performance indicators	Feedback report Recommendations Descriptive measures New tools

Investigation outcome:

- Understand the use of performance measurement indicators within maintenance
- Feedback on the current effectiveness of your maintenance function
- Validation of my research

Appendix D

Post research feedback

D1 Introduction

For all involved with this research, the opportunity to provide feedback was given. For the companies consulted during the pre-case study investigations opinion was sought regarding the usefulness and value of the tools, techniques and approaches used by the researcher. The major and minor case study participants were provided with copies of the final case reports as well as publications directly related to the research undertaken. Attendees of the 13th International Maintenance Management Conference 2002 (Australia) and recipients of a maintenance journal article directly related to this research also provided additional feedback. The following sections highlight the feedback provided in the form of e-mail correspondence, personal and telephone interviews with participants of the research.

D2 Feedback from research investigations

All participants of the case study research and company visits were sent letters seeking their opinion of the research undertaken. Each company visited were asked identical questions relating to the use and applicability of the overall measure of maintenance performance. The issue of lean concept use, acceptance and usefulness overall to those being investigated were clarified during company visits and subsequent case study investigations. Three companies chose to respond to the request for feedback: Nissan manufacturing (UK), Land Rover (UK) and Ford (Dagenham stamping operations) (UK). Mark Sutcliffe, head of engineering Nissan (UK) replied directly to an e-mail request. Pat Jones, Head of maintenance and technical services Land Rover (UK) provided feedback during a telephone interview. Lee Turner as a senior production supervisor / manager at Ford Dagenham introduced through interview and e-mail Matthew Pears a senior maintenance supervisor who became involved with the research and was subsequently interviewed post research.

D2.1 Feedback questions to research participants

Six questions were asked of each research participant, these were:

- Q1** How do you perceive the usefulness of my performance measures?, e.g., ease of use, ease of understanding etc.
- Q2** Do you feel that the performance measures could make a practical contribution to your maintenance function?
- Q3** The overall measure of maintenance performance was purposefully developed to be fully descriptive and modular in construction to suit different types of maintenance practice. As such, some potential users may find that the overall measure of performance too comprehensive to use
- Q4** Do you feel that a reduction in the number of individual indexes would compromise, improve, or have little effect on the integrity of the overall measure?
- Q5** In your view how useful are the measures of the maintenance function within the context of overall business performance
- Q6** Are there any other comments you wish to add? If so, please feel free to include them. For example, are there any indices in particular that you would use to measure overall maintenance performance? Are there indices you would not use? Could you benefit from a revised set of performance measures for your own use?

D2.2 Nissan UK feedback

E-mail correspondence from Mark Sutcliffe head of engineering Nissan UK:

----- Original Message -----

From: Sutcliffe, Mark

To: 'Chris Davies'

Sent: Thursday, February 07, 2002 4:44 PM

Subject: RE: Chris Davies, Cranfield University

Chris

I have made some basic comments. I hope they help. Sorry I never got the full data to you but the new model launch work took over all such activities. I would be very interested to read what you have presented so far.

Best regards

Mark

Q1 How do you perceive the usefulness of my performance measures?, e.g., ease of use, ease of understanding etc.

- *Whilst the terminology required definition at the outset, the measures are easy to use and understand*

Q2 Do you feel that the performance measures could make a practical contribution to your maintenance function.

- *Yes, even though many of these measures are used in isolation, the method of combining them together adds value. The use of a smaller number of combined indicators allows rapid understanding of progress*

Q3 The overall measure of maintenance performance was purposefully developed to be fully descriptive and modular in construction to suit different types of maintenance practice. As such, some potential users may find that the overall measure of performance too comprehensive to use

- *The beauty of the modular approach is that you can take parts and leave parts as suits the application. I do not believe this comprehensive approach to pose a problem*

Q4 Do you feel that a reduction in the number of individual indexes would compromise, improve, or have little effect on the integrity of the overall measure?

- *If individual indices could be eliminated without adversely affecting integrity then this should happen.*

Q5 In your view how useful are the measures of the maintenance function within the context of overall business performance?

- *The measures are a useful addition to the current accepted methods of measuring performance. Whenever efforts are made to deliver improvements then a comprehensive measurement method is essential*

Q6 Are there any other comments you wish to add? If so, please feel free to include them. For example, are there any indices in particular that you would use to measure overall maintenance performance? Are there indices you would not use? Could you benefit from a revised set of performance measures for your own use?

D2.3 Land Rover UK feedback

Post research feedback Pat Jones Head of Maintenance and technical services within Land Rover was interviewed by telephone. A transcript is given here. Prior to inclusion, Pat Jones was given a copy for his consideration and agreement.

Q1 How do you perceive the usefulness of my performance measures?, e.g., ease of use, ease of understanding etc.

- *Had we had any problems understanding the measures and their purpose, we would have brought it to your attention during the visits and telephone conversations. The layout of the spreadsheet application you also provided not only made the measures easy to understand but also easy to use.*

Q2 Do you feel that the performance measures could make a practical contribution to your maintenance function.

- *Yes*

Q3 The overall measure of maintenance performance was purposefully developed to be fully descriptive and modular in construction to suit different types of maintenance practice. As such, some potential users may find that the overall measure of performance too comprehensive to use

- *After a few minutes it becomes clearer what the purpose is, and how each level can be used by different people. Understandably, if the measures can be suited to our exact needs by eliminating some of the modules then that would be good*

Q4 Do you feel that a reduction in the number of individual indexes would compromise, improve, or have little effect on the integrity of the overall measure?

- *You have obviously designed the measures to be used as a whole, with the option to reduce the quantity to suit a particular industry or department. As for compromise or improvement, who knows until they are put into use? However, if they can be modified so that the number of measures can be reduced to suit our own needs at any particular time in the future could be worthwhile*

Q5 In your view how useful are the measures of the maintenance function within the context of overall business performance?

- *Any form of measure for improvement that could justify itself and the environments in which they are used would be very useful in terms of supporting the business*

Q6 Are there any other comments you wish to add? If so, please feel free to include them. For example, are there any indices in particular that you would use to measure overall maintenance performance? Are there indices you would not use? Could you benefit from a revised set of performance measures for your own use?

- *Some of the measures certainly look interesting enough to use as part of daily / weekly / monthly progress feedback. Technical services, maintenance, and production are working together looking at which individual measures may be easily integrated with current methods of performance measurement. The only problem we can envisage at the moment by revising your measures, is the future maintainability of their use by shopfloor staff and technicians. However, I also feel that this has as much to do with the newness of measures rather than anything else*

D2.4 Ford (Dagenham stamping operations) UK feedback

Lee Turner, a senior production supervisor and Matthew Pears a senior maintenance supervisor within Ford Dagenham were interviewed regarding the research. Based on subsequent meetings, e-mail contact with both and final telephone interview with Matthew Pears, the following transcript is given here. On completion Matthew was given a copy for his consideration and agreement.

Q1 How do you perceive the usefulness of my performance measures?, e.g., ease of use, ease of understanding etc.

- *After your brief explanation the measures were easy to understand. As for their usefulness, we are proposing to use a number of your measures within the department.*

Q2 Do you feel that the performance measures could make a practical contribution to your maintenance function.

- *Yes, as individual measures, technicians should be able to follow progress within their part of the plant. Should all the modules be combined, then I can see how the measures could help provide an overall picture of maintenance effectiveness*

Q3 The overall measure of maintenance performance was purposefully developed to be fully descriptive and modular in construction to suit different types of maintenance practice. As such, some potential users may find that the overall measure of performance too comprehensive to use

- *As a comprehensive measure, I cannot see any problem in using it as such. However, as stated, if it can be modularised then obviously we should be able to pick and choose the measures we need*

Q4 Do you feel that a reduction in the number of individual indexes would compromise, improve, or have little effect on the integrity of the overall measure?

- *If the measures can be reduced without affecting the overall measure then why not. However, I have noticed that for us, some of the measures do repeat themselves in terms of how we would use them*

Q5 In your view how useful are the measures of the maintenance function within the context of overall business performance?

- *For justification of improvements and change then the measure could be useful. How the business itself is measured I couldn't tell you. However, if the need arose then maintenance should be able to justify itself to the business as a whole*

Q6 Are there any other comments you wish to add? If so, please feel free to include them. For example, are there any indices in particular that you would use to measure overall maintenance performance? Are there indices you would not use? Could you benefit from a revised set of performance measures for your own use?

- *At the moment, I am discussing with Lee Turner in production what measures we can use as a combined effort to maintain progress of improvement and change throughout. We are seeking to use ten or so measures to start with that would be easy to collect, provide feedback of effort, and somehow reflect upon bottom line cost savings. When this has been established, we will be looking at implementing more of your measures*